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Tidal Power and Canada

- A Review -

Renewable Energy Branch

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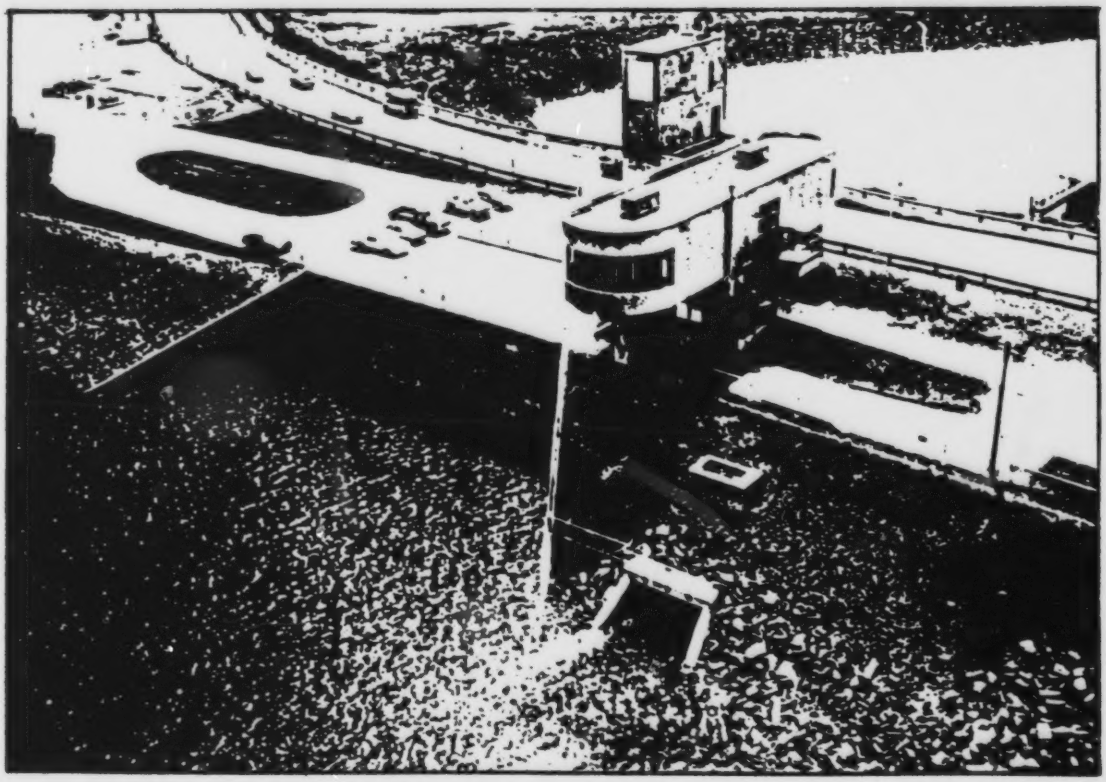
Prepared by:
R.H. Clark, P.Eng.
Consulting Engineer - Small Hydro
1461 McRobie Avenue
Ottawa, Ontario
K1H 7E2

Scientific Authority:
T.T.P. Tung
Technology Coordinator - Hydraulics
(613) 996-7518



Annapolis Tidal Generating Station

FOREWORD

During the past two decades there has been periodic, intensive study regarding the technical and economic feasibility of the exploitation of the.energy of the Bay of Fundy tides. The past decade has also seen an intensifying interest in data collection and research related to the ecosystems dependent upon the established tidal regime.

The purposes of this report, prepared under contract with Energy, Mines and Resources Canada (Contract Serial No. EMR-FPS-86-0003), are: (i) to summarize the developments to date on tidal power activites world wide; (ii) to review recent engineering investigations of the Bay of Fundy potential; and, (iii) to identify the principal technical and environmental issues still requiring resolution.

AVANT-PROPOS

Au cours des deux dernières décennies, des études détaillées ont été consacrées périodiquement à la faisabilité technique et économique de l'exploitation de l'énergie marémotrice dans la Baie de Fundy. On observe également depuis une dizaine d'années un intérêt croissant pour les cueillettes de données et les recherches ayant pour objet les écosystèmes tributaires du va-et-vient habituel des marées.

Préparé à titre contractuel pour Énergie, Mines et Ressources Canada (Contrat n° EMR-FPS-86-0003), le présent rapport vise à : (i) résumer les progrès réalisés jusqu'à présent dans le domaine de l'énergie marémotrice sur la scène mondiale; (ii) examiner les récentes études techniques du potentiel de la Baie de Fundy; (iii) cerner les principaux problèmes techniques et environnementaux à résoudre.

EXECUTIVE SUMMARY

The past quarter-century has seen a re-awakening of interest in exploiting the energy in the tides of many estuaries around the world. This surge in interest was sparked by the large increases in oil prices in the early 1970's and, more particularly, as a result of the initiation in 1960, the completion in 1967 and the successful operation since that time of the first large commercial, tidal electric plant at the mouth of La Rance estuary.

A number of office studies, sometimes supported by field investigations, have been carried out for specific locations along the coasts of Australia, Argentina, Brazil, Canada, China, France, Korea, India, Union of Soviet Socialist Republics, United States and the United Kingdom. Some of those studies which have shown some promise are reviewed briefly. Current estimates place the total capacity of all possible tidal electric plants in the order of one million megawatts with an expected output of, perhaps, three thousand terawatt hours.

Following the first comprehensive examination of the Fundy tidal power resource in 1966-69 by the Atlantic Tidal Power Programming Board, there was a succession of investigations: first, by the Tidal Power Review Board (1976-77); then, an update of that Board's study by the Tidal Power Corporation (1981-82), particularly with respect to the Minas Basin site (B9); and, finally, the more recent update by Alcan in 1984-85 with particular reference to Site A8 at the mouth of Cumberland Basin.

The Tidal Power Review Board introduced a number of improvements to upgrade the results of tidal investigations, such as: arranging for the acquisition of accurate tidal data and the development of a competent hydrodynamic mathematical tidal regime model; confirming the feasibility and superiority of caisson construction; applying utility system planning techniques; and developing a competent economic analysis framework. The Board also launched the first efforts to understand the environmental consequences of operating a tidal electric plant in the Bay of Fundy. The results indicated that the life cycle benefits would exceed costs by a margin of 20%. The 1982 Update reflected changes in costs, improved marine construction techniques and changes in energy prices and policies with the result that the benefit to cost ratio improved substantially, to become about twice as great as in 1976.

There was a growing consensus that, although the unit cost of energy from a smaller plant at Site A8 would be greater than that from the larger capacity site in Minas Basin (B9), the output from A8 would still be substantial, its financing less difficult and its environmental impact significantly less severe. In 1984, Alcan undertook to manage a study, funded under the Canada-Nova Scotia Oil Substitution and Conservation Agreement, to determine more closely the technical and economic aspects of Site A8 and whether conditions were sufficiently favourable to warrant undertaking pre-commitment activities. It was determined that, although the energy output from the natural tidal rhythm could compete in the United States market with the cost of energy generated from fossil fuels, that market is not currently interested in cyclic power supply, such as that from the natural rhythm of the tides. There would, however, be substantial interest if such energy could be economically retimed to a firm supply which would serve as the equivalent of additional dependable capacity.

Since the Review Board's reassessment studies, substantial research programmes have been carried out yielding significant insight on the ecological and environmental effects from the operation of a tidal plant in the upper reaches of the Bay of Fundy. It is now possible to say, with a high degree of accuracy, that, with respect to the operation of a plant at Site A8, there would not be impacts sufficiently adverse as to prohibit development. The costs for mitigation of any adverse impacts could be internalized.

Also, since the reassessment studies, the hydrodynamic mathematical model has also been improved to provide better predictions on tidal current changes, mixing processes and sedimentation changes. A hybrid (hydraulic/mathematical) model has been constructed and successfully tested. The hybrid model consisted of an hydraulic model of Cumberland Basin driven by the mathematical model of the Bay of Fundy/Gulf of Maine system. Such a model will enable detailed hydraulic model tests to be carried out with precision to check construction procedures, caisson placements and sedimentation processes under the large tidal influences at Site A8. Research is currently underway, to be completed this year, to develop further operating data with respect to fish mortality through tube-type turbines, to test behavioural devices for effective fish diversion and to determine the cost of retiming the energy output of a plant at Site A8 by the use of a compressed air energy storage system.

The United Kingdom Department of Energy has also recently undertaken several pre-feasibility investigations of the tidal potential in the Severn Estuary and a more advanced investigation has just been launched in collaboration with the private sector. There are many aspects common to the two studies such that the techniques and results for one estuary could be applicable with slight modification to the other estuary. Thus, there would be merit in cooperating, and possibily coordinating, study activities for the Bay of Fundy and the Severn Estuary.

A tidal plant at Site A8 could be a major regional asset in the Maritime energy picture with a useful life of about a century, with no fuel cost, a significant hedge against inflation of energy costs, no environmental pollution loading and a reduction of energy costs over the longer term.

SOMMAIRE

Le dernier quart de siècle a vu renaître un intérêt pour l'exploitation de l'énergie des marées à l'emplacement de nombreux estuaires dans le monde. Cette vague d'intérêt découle, certes, de la forte hausse des prix du pétrole survenue au début des années 1970, mais aussi de la mise en service de la première grande centrale marémotrice commerciale, à l'embouchure de l'estuaire de la Rance. Construite de 1960 à 1967, cette centrale est exploitée avec succès depuis le début.

Un certain nombre d'études, parfois étayées d'enquêtes sur le terrain, ont été effectuées en vue de déterminer des sites précis sur les côtes de l'Australie, de l'Argentine, du Brésil, du Canada, de la Chine, de la France, de la Corée, de l'Inde, de l'Union soviétique, des États-Unis et du Royaume Uni. Quelques-unes des études prometteuses sont examinées brièvement. On estime actuellement à un million de mégawatts la capacité totale des centrales marémotrices possibles; leur production pourrait atteindre 3 000 terawatts-heures.

Une série d'enquêtes a fait suite au premier examen détaillé des ressources énergétiques de la Baie de Fundy, réalisé de 1966 à 1969 par le Bureau des études marémotrices de l'Atlantique. Notons d'abord les travaux du Comité de révision des études marémotrices (1976-1977); suivis d'une mise à jour de l'étude de ce comité par la Société d'énergie marémotrice (1981-1982), particulièrement en ce qui concerne le site du bassin Minas (B9); enfin, la mise à jour la plus récente effectuée par Alcan en 1984-1985, qui porte principalement sur le site A8, situé à l'embouchure du bassin de Cumberland.

Afin de parfaire l'étude de l'énergie marémotrice, le Comité de révision des études marémotrices a, entre autres, vu à l'acquisition de données précises sur l'énergie marémotrice et à la mise au point d'un modèle hydrodynamique mathématique de régime de marée; confirmé la faisabilité et la supériorité de la construction par caissons; planifié des systèmes pour les services publics et élaboré un cadre d'analyse économique efficace. Le Comité a également été le premier à tenter de cerner les

conséquences environnementales de l'exploitation d'une centrale marémotrice dans la Baie de Fundy. Selon ces études, les bénéfices engendrés tout au long de la durée d'exploitation de la centrale excéderaient les coûts de 20 %. La mise à jour de 1982 rendait compte de coûts différents, de meilleures techniques de construction maritime, de nouveaux prix et de nouvelles politiques énergétiques, ce qui a révélé une nette amélioration du ratio avantages-coûts, qui a presque doublé par rapport à 1976.

De plus en plus, on convenait que le coût unitaire de l'énergie produite par une centrale de plus petite taille au site A8 serait plus élevé que celui de l'énergie d'une centrale de plus grande capacité au bassin Minas (B9). Toutefois, les installations du site A8 produiraient une quantité d'énergie importante, comporteraient moins de difficultés de financement et auraient des conséquences beaucoup moins néfastes sur l'environnement. En 1984, Alcan a commencé à diriger une étude financée en vertu de l'Accord Canada--Nouvelle-Écosse sur les économies et le remplacement de pétrole, afin de mieux cerner les aspects techniques et économiques du site A8 et de déterminer si les conditions lui permettaient d'entreprendre des activités préalables à un engagement. Il a été déterminé que même si la production énergétique générée par le rythme naturel des marées pourrait être compétitive sur les marchés américains par rapport au coût de l'énergie des combustibles fossiles, le marché ne s'intéresse pas pour l'instant, aux sources d'énergie cycliques de ce genre. Toutefois, ce concept susciterait un grand intérêt si les rythmes de production pouvaient être rajustés économiquement de manière à procurer une capacité supplémentaire fiable.

Depuis que le Comité de révision a réévalué la situation, d'importants programmes de recherche ont procuré un bon aperçu des effets écologiques et environnementaux de l'exploitation d'une centrale marémotrice sur le cours supérieur de la Baie de Fundy. On peut maintenant affirmer, preuves suffisantes à l'appui, que l'exploitation du site A8 n'entraînerait aucune conséquence environnementale pouvant empêcher l'aménagement d'une centrale. Les coûts entraînés par l'atténuation de toute conséquence négative pourraient être assumés à même le financement interne.

Depuis qu'ont eu lieu les études du Comité, le modèle hydrodynamique mathématique a également été mis au point de façon à permettre de mieux prévoir les changements des courants de marée, les processus de mélange et les modifications de la sédimentation. Un modèle hybride (hydraulique et mathématique) a été réalisé et les essais ont été concluants. Il consiste en un modèle hydraulique du bassin Cumberland conçu à partir du modèle mathématique des marées de la Baie de Fundy et du golfe du Maine. Il permettra d'effectuer avec précision des essais détaillés de modèles hydrauliques afin de vérifier les méthodes de construction, l'utilisation des caissons et les processus de sédimentation en fonction des fortes marées observées au site A8. Des recherches en cours, censées se terminer cette année, permettront de prévoir les conséquences de l'utilisation de turbines bulbes à rotor périphérique sur les populations de poissons, de mettre au point des techniques efficaces pour détourner le parcours des poissons et de déterminer le coût du rajustement du rythme de production énergétique d'une centrale au site A8 au moyen d'un système de stockage d'énergie par compression d'air.

Le ministère de l'Énergie du Royaume-Uni a également entrepris récemment plusieurs études de faisabilité préliminaires relativement au potentiel marémoteur de l'estuaire de la rivière Severn, et une enquête plus détaillée vient tout juste de commencer en collaboration avec le secteur privé. Ces deux études ont de nombreux aspects en commun, de telle sorte que les techniques et les résultats applicables à un estuaire pourraient être utilisés, moyennant quelques modifications, pour un autre cours d'eau. Il serait profitable que les études consacrées à la Baie de Fundy et à la rivière Severn soient exécutées en collaboration, voire coordonnées.

Une centrale marémotrice au site A8 constituerait une richesse régionale d'importance dans le secteur énergétique des Maritimes. En effet, elle aurait une durée d'utilisation d'environ un siècle, n'entraînerait aucun coût en combustible, serait une protection efficace contre l'inflation des coûts de l'énergie, ne polluerait pas l'environnement et permettrait une réduction des coûts de l'énergie à long terme.

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TIDAL POWER AND CANADA - A REVIEW

I - INTRODUCTION

The geography of the Bay of Fundy, where the tidal range is probably the highest in the world, promotes a concentration of tidal energy which has fostered many attempts to harness this renewable energy resource on Canada's east coast.

Theoretically, any tide anywhere can produce power in some quantity from the energy otherwise dissipated during its ebb stage. However, there are relatively few locations in the world where topographical conditions are such as: (i) to cause the incoming tide to rise to an unusual or abnormal height; and, (ii) to permit a stable barrier to be placed in the path of the tide, provided with openings to allow the tidal flow to pass through to its culminating level and, thereupon, capable of being closed to hold this level as the tide recedes on the seaward side of the barrier. For this situation, it follows that as the tide recedes seaward or "ebbs", a gradually increasing head differential is created between the falling seaward levels and the fixed level held above and within the barrier, designated the "tidal basin". When this head differential has reached some pre-determined value, the tidal flow impounded by the barrier now possesses a potential energy which can be converted into controllable mechanical or electrical power. Thus, in addition to a sufficiently high tidal range, the site should also include a natural bay with an adequate area and volume and be so situated that the operation of the plant will not significantly reduce the tidal range.

There are two limitations associated with the production of this power. Firstly, there will necessarily be a constantly varying rate of power potential within the cycle of ebb and flow. Secondly, a similarly recurring cessation of all power production during a period which begins when the rising tide, coupled with the falling head in the tidal basin, has obliterated the operable head, and ends when the tide has receded to a level resulting in the predetermined minimum operating head at which the turbine can function and with the tidal basin again full to high slack level. In principle, therefore, a simple tidal development can only produce power intermittently within the daily tidal cycles.

Some Tidal Characteristics

Ocean tides: On the shore of an ocean the water level rises and falls, a fluctuation which occurs twice each day or, more precisely, twice every 24 hours, 50 minutes and 28 seconds - the apparent period of rotation of the moon. Primarily due to the upward gravitational pull of the moon, the water level will gradually rise till it reaches its highest point termed "high water", and then fall till it reaches its lowest point, or "low water", when it turns and rises again. The difference between these two points is called the "range" of the tide. In any tidal power scheme it is the range of the tide which determines the potential head available for actuating the turbines, although the sluiceway capacity and operating characteristics of the development will have a bearing on the amount of this head that can be used.

The tide in the various oceans progresses through them as an undulation; for example, the tide runs up the Atlantic Ocean as an undulation from its south end between South America and Africa, to its north end between Canada and Europe (Dawson, 1920). The range of these oceanic tides is usually not more than about 1 m.

The ocean tide is produced primarily by fluctuations in the resultant of the several forces of gravity and of centrifrigal action caused by the earth's rotation and by changes in the relative positions of the earth, moon and sun. Thus, the force causing the tide at any point on the earth is substantially the resultant of the attractive forces due to the moon and sun and the centrifugal force caused by rotation of the earth-moon system (Dean, 1966).

Because it is so much nearer the earth than the sun, the moon, despite its comparatively small size, exerts a much greater influence on the tides than does the sun, since attractive force is proportional to the inverse square of the distances between the bodies. In theory, the solar tide is 46 percent of the lunar. Hence, a knowledge of the relative movements of the sun, moon and earth is necessary for an understanding of the tides and particularly, of the variations in the range which take place in a systematic manner over a long period of time.

The amount of rise and fall of the tide is not the same everywhere; it varies from almost nothing to a range of over 17 m in some localities. On the other hand, in all parts of the world, the time of high water is not always at the same hour of the day but, on the average, it occurs about one hour later from one day to the next and in a period of 14 to 15 days it comes around to the same hour again. At every locality in every ocean there is also to be found a well-marked variation in the range of the tide which usually recurs twice in the course of each month. This variation may be very different in its character from region to region; for example, it may be a change in the range of the tide from a large difference in level to a small difference or the two tides of the day (semi-diurnal tides) may sometimes be exactly equal in their range and at another time, one of the two maybe be much greater than the other, alternately. There are some localities where at certain times of the month the tide becomes diurnal, i.e. with only one high water and one low water during the day, but the reason for such exception does not conflict with the general principles. However, whatever the character of the variation may be, the change always recurs in a period of either about two weeks or about a month in every ocean.

Propagation of tides in estuaries: When the tide leaves the open ocean and enters straits, inlets, bays and estuaries, it undergoes a change which is more closely related to the laws of hydraulics and wave motion than to its astronomical aspects. An elaboration of the physical understanding of the tidal flows in estuaries is presented by Ippen and Harleman (1966).

Throughout the ocean, the tide is almost always a symmetrical undulation, having the same form as the long swell of the ocean; the summit of the undulation causing high water and the trough, low water. On entering an estuary the form of the undulation undergoes the same kind of modifications that waves do in shallowing water near the shore. The observed sea level is raised and, depending upon the configuration of these inlets, the amplitude of the tidal wave may be increased many times (the term "tidal wave" should not be confused with the tsunami, a seismic phenomenon). Such a wave tends to move along an estuary with a speed given by $\sqrt{gd}$, where d = mean depth. To illustrate, if the mean depth of an estuary were 50m, then the wave length L = wave period x speed = $44{,}700 \times 22.14 \times 10^{-3} = 990$ km (approx). The period of a semi-duirnal ocean tide of 12 hours and 25 minutes (12.42 hours) is long enough to make the wave length much longer than the physical length of an estuary. Although most estuaries are shorter, one with a length that is about one-half or one-quarter the wave length would impart a resonant response, and the amplitude of the tide could increase along the estuary by factors of four or more.

For example, the Bay of Fundy has an overall resonant frequency which is essential to the production of the very high tidal amplitudes at the head of the Bay. The narrowing and shelving of the Bay of Fundy brings the whole system, from the Continental Shelf through the Gulf of Maine to the upper reaches of the Bay of Fundy, to near resonance with the semi-diurnal tides. From a comparison of the principal solar and lunar ecliptic tidal harmonics of the Bay of Fundy/Gulf of Maine system with amplitudes in the North Atlantic Ocean, it has been determined that the system behaves as if its natural period were approximately 13 hours. Thus, along the outer edges of George's Bank, the oceanic tide has a mean range of about 1 m; at the mouth of the Bay of Fundy, the tidal range has increased to about 3.5 m (at Yarmouth, N.S.), to a mean range of about 13 m in Cobequid Bay and 11 m in Cumberland basin. The tide at Cape Maringuouin (at the mouth of Shepody Bay) occurs about 40 minutes later than at the mouth of the Bay of Fundy; within Minas Basin, the time of high water occurs even 40 minutes later than it does outside that Basin.

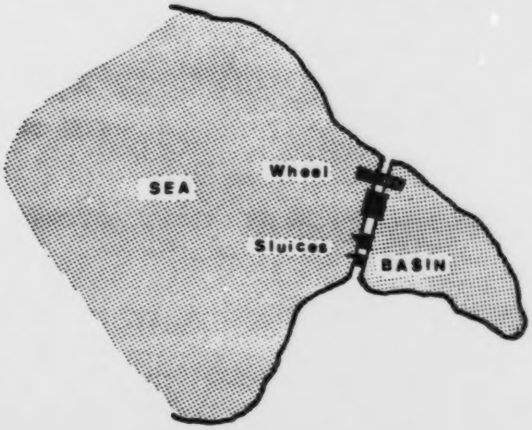
Regardless of local variations, tides occur in a most orderly fashion and are predictable. Both the periodicity and predictability of tidal action are important characteristics bearing strongly on the utilization of this phenomenon as an energy source. Tides at any location repeat themselves almost identically about every 19 years. Within any one year interval, the differences are relatively small so that the available energy is practically the same from year to year. Moreover, at least for the semi-diurnal tides, there is a basic relationship between the tidal range and hours of high and low tide so that, at a particular location, the tidal range at a specific time during the day will always be within a known maximum value.

Barrier effect: A most important effect, from the point of view of tidal electric engineering, is that which a barrage or tidal development may have on the resonance of an estuary. The barrage could increase the tides at the barrier because it would bring the foreshortened estuary closer to resonance or it could reduce materially the tidal range by upsetting the natural resonant condition. Thus, it is very important early in an investigation to be able to simulate the natural tidal regime and then to determine the effect on this regime by the placement of the barrage at various locations within the estuary as well as by the operation of the development. Mathematical models are now an invaluable tool in simulating a tidal regime to determine the effects of construction and operation of a tidal electric plant on that regime.

Historical Development of Tidal Power

According to historical records, inhabitants of the coastlines, particularly those bordering the North Atlantic, installed simple tidal mills on the shores of Gaul, Andalusia and England, at least as early as the Middle Ages, to carry out some of the more tedious tasks, such as grinding corn. It is likely that tidal energy was tapped by other countries, perhaps even earlier.

The tidal mill is a version of the conventional water mill but required just a little extra skill and care to operate it. The dam, closing off the small bay or mill pond from the sea, was equipped with sluice gates or 'flap' gates. These opened automatically with the tidal current during the flood and closed during the ebb to trap the water in the mill pond; from there it was directed to drive a large-diameter, wooden paddle wheel and thence back to the sea. A typical tidal mill layout is shown by the following sketch:



These ancient mills used the ebb tide for the generating cycle and the engineering skill of those who built them is to be admired. The great driving wheels made of wood and subsequently of cast iron, mostly with replaceable wooden teeth, matched exactly the smaller wheels which they operated. Many mills were automated to the extent that they could be operated by one person who had, readily available, a series of ropes and pulleys by which any part of the mill's machinery could be set in motion. At those locations with semi-diurnal tides, operation was possible twice daily for periods of about five hours each - but the times of generation would progress through the solar day during a lunar month. Since the tidal cycle and solar cycle are out of phase in most locations around the world, the miller had to mill when the tide was right - whether at midnight or midday - an early example of flexible working hours.

The earliest records on tidal mills date from about the 11th century. For the next several centuries, many tidal mills were reported to have been in operation along the Atlantic Coast of Europe, mostly in Great Britain, France and Spain. One such installation in the Deben Estuary (England) was mentioned as early as 1170 in the records of the Parish of Woodbridge. Although the present building there dates from the 18th Century, the mill was in operation until 1957 when the main wheel shaft broke. Since then, the mill pond has been converted into a yacht marina and the mill restored as a museum piece.

Two tidal mills were still in operation in the Rance estuary when Electricité de France began work leading to the construction of the world's first large, modern tidal electric power plant. Tidal energy was tapped as early as 1607 in North America. Slade's Mill in Chelsea, Massachusetts was built about 1734 to grind spices and it developed about 50 horsepower (about 35 kW). Prior to 1800, at least two small, single-basin tidal mills were in existence in Passamaquoddy Bay. According to Wylie (1979) Peveril Meigs found sites of more than 300 tide mills on the Atlantic coast from Maine to Georgia. Also according to Bernshtein (1965), there were tidal mills in Russia as early as the 18th Century.

Besides the use of the simple water wheel turned by the tide and connected by belts or gears to grinding or "mill" stones, relatively primitive devices were developed to harness the tidal energy for other uses, such as for pumping. Even in 1824, part of the water supply of London was still provided by 6 m diameter water wheels installed in 1580 under the arches of London Bridge. Some of these stuctures for transforming tidal energy were of impressive size. A tidal mill, built at the beginning of the 18th century on the shores of Rhode Island, United States, had 3.36 m diameter wheels which were 7.92 m in width and weighed about 20 tons.

Many ingenious methods, in addition to the water wheel, have been formulated to use the potential energy of the tides or the kinetic energy of the tidal currents, or combinations of both, by means of such devices as lifted platforms or weights and air compressors. At least 300 patents have been registered during the past 100 years for different technical systems to extract the energy of the tides. Most of these schemes are visionary and unworkable. However, all methods had one common characteristic - they were devised to transform the energy of the tides into mechnical energy for local consumption.

An interesting survey, with an extensive bibliography, of the development of the use of tidal power from classical times to the completion of La Rance tidal electric plant in 1967 is presented by Charlier (1969).

The advent of the Industrial Revolution introduced insatiable demands for power and energy on a large scale. The exploitation of tidal energy fell into disuse because hydroelectric possibilities of rivers and fossil-fuel fired power plants offered easier technological access to power generation on an industrial scale. The advances in technology for the development of these latter sources of power resulted in the neglect of tidal power technology. The small tidal mills, producing perhaps the equivalent of up to 75kW for use at the site (an infinitemally small fraction of the potentially available energy) could not meet the competition and disappeared from the scene - monuments of a technology that had outlived its day.

Hydroelectric vs Tidal Electric Developments

River hydro power and tidal may have many characteristics in common but there is a fundamental difference in the forces activating these two energy sources. These forces are the downward-acting terrestrial gravitation causing the water to flow on the earth's surface, and the upward-acting lunar gravitation causing the water to oscillate in estuaries. There has been a tendency to ignore this basic dissimilarity in the driving forces and to treat tidal electric developments simply as low-head hydroelectric developments with added complications.

The approaches to the hydraulics and to the machinery and plant design and construction are also different for river hydro and tidal power developments. The most economical design for the former development is determined by the hydrologic characteristics of the river, such as its minimum recorded flow, flood flows, storage possibilities and head. For a tidal development, on the other hand, the design can be varied to produce the desired capacity. Thus, the output of a tidal plant is determined by the following interrelated factors: (i) usable head which varies continuously with the tidal regime and is modified by the fluctuation of basin levels resulting from operation of the plant, (ii) the area of the tidal basin; (iii) the capacity of the sluices used to fill or empty the basin; (iv) the capacity of the generating units; and (v) the method of operation selected.

Because of the abundance of water available to a tidal plant, emphasis of design is more on maximum output than on maximum efficiency, the latter being of more importance in river hydro developments. Thus, the conversion of tidal energy differs completely from that of hydro energy where it is usually not too difficult to ascertain the order of magnitude of the head, mean discharge and spillway capacity. Because of its continually changing head, it is impossible to determine a priori the dimensions of the equipment and the magnitude of the installed capacity for a tidal electric development. Optimization is a fundamental requirement in the design of a tidal power project.

Morever, the water quantity involved in tidal cycle is relatively constant so that, with tidal energy, there is no wet or dry year and, even more important, no wet or dry month - no summer or winter. In contrast with the foregoing characteristics, river energy production is fraught with unpredictable wet and dry cycles. On the other hand, it is possible to predict the amount of tidal energy available in a week, a month or a year, except for minor effects of meteorological influences on the water surface.

The spillway gates of a river hydro plant may have to be operated only a few times annually to maintain the reservoir level within its prescribed limits or to act as a relief valve to prevent overtopping of the dam. In a single-basin, ebb-generation tidal power scheme, the sluiceway gates would be operated at least 1400 times annually and about twice that for double effect operation, to allow, alternatively, the filling and emptying of the basin.

Tidal Schemes and Modes of Operation

Developing technology, given impetus by the Industrial Revolution, has been responsible for the emergence in this century of large electric power and energy supply systems. Long distance electrical transmission has freed tidal energy from the limitation of at-site consumption. Moreover, the extremely low and variable heads of a tidal cycle can now be efficiently exploited by low-head hydraulic turbines capable of generating and of pumping in both directions, making available four modes of operation in a development. Marked advances have also been made in the technology of construction in a marine environment and in the mathematical understanding of tidal cycle variations. The complex nature of the tidal energy problem required the development of mathematical modelling techniques which, with the aid of high-speed electronic computers, enable each area to be investigated at the moderate cost and the energy yields and tidal effects of alternative development alignments and modes of operation predicted.

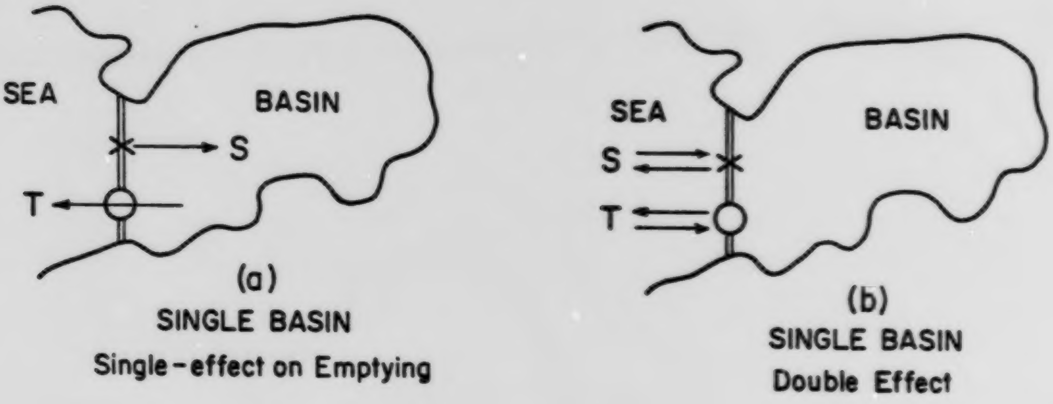
Efforts to rationalize tidal power technology were undertaken centuries ago. A handbook for the construction of tidal mills was written by an Italian, Mariano, in the 15th century. At the beginning of the 18th century, a Frenchman, Belidor, considered the quality of tidal energy. In his treatise on hydraulic architecture, he stated principles for multi-basin operation to achieve some continuity of energy output.

The problem of continuity is one of the main disadvantages of tidal power. Tidal energy is, of course, tied to lunar timing, with semi-diurnal and monthly (lunar month) cycles. The lunar cycle is constantly drifting into and out of phase with the solar cycle and hence, with industrial power demands which are geared to the latter. This was a major problem but is now less important as power systems have grown to encompass a diversity of power sources and methods of energy storage have been developed and are now routinely employed. Moreover, as a result of recent advances in technology, a tidal power plant is now more versatile in output than it was.

Many modes of operation of a tidal development have been proposed to provide a capacity component to its output and/or develop continuous power to create an equivalence between a tidal electric plant and a conventional electric power source with respect to both energy and firm capacity. Such schemes have been discussed extensively in many publications (Bernshtein, 1965; Gray and Gashus, 1972). There are four practical concepts for exploiting the energy from the tides, based either on the simple tidal mill concept or on the use of two basins, and these are described briefly in Appendix A. The several detailed studies of the Bay of Fundy potential have confirmed that a single-basin scheme will yield the lowest cost per kWh.

The simple tidal mill concept requires a bay or estuary to be closed from the sea by a barrier or dam fitted with sluices. When the tide rises, the sluices are opened and the water rushes in to fill the basin. At high tide, the sluices are closed and the ebbing sea level gives rise to a head between the basin and the sea level. If a powerhouse, equipped with turbo-generators, forms part of the dam, it is only necessary to let the water run through the turbines to retrieve energy from the tidal water. This is the principle of the tidal mill and is the simplest engineering solution. It is known as "single-effect" operation and the energy is produced when the basin is emptied to the sea. With somewhat more sophistication, the turbines can be designed to operate not only in the basin-to-sea direction but also in the sea-to-basin direction. This is known as "double-effect" operation; this capability is built into the La Rance tidal power development in France.

Figure 1 shows the operational concepts of a single-basin plant and the typical output from a single effect installation when the plant is operated for maximum energy production during a tidal cycle. The shaded area shows the variable output as two 'slugs' of energy.


SEA
BASIN
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SEA
BASIN
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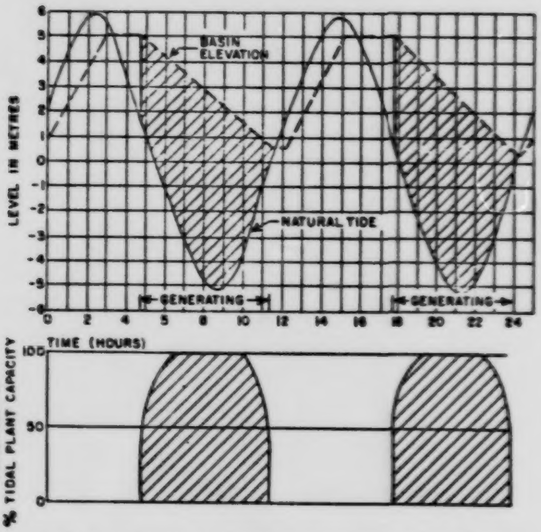
(a)
SINGLE BASIN
Single-effect on Emptying

(b)
SINGLE BASIN
Double Effect



OUTPUT FROM SINGLE-EFFECT SCHEME

Figure 1. Single basin concept.

Merits of Tidal Power

The attractiveness of tidal energy stems from the following features:

1. it derives from the exploitation of an indigenous resource of renewable energy;
2. the technology for exploitation is available and is proven;
3. many of the characteristics of river hydroelectric plants apply also to tidal electric plants, viz. long plant life and annual costs which are almost completely dependent upon the magnitude of the investment costs;
4. the tides are an energy source completely and accurately predictable as far into the future as it is necessary to consider;
5. the exploitation of the tides for electrical energy generation is non-polluting; and,
6. the exploitation of Fundy tides on a commercial scale has been demonstrated by several competent feasibility studies.
7. the resource is freely available and, therefore, involves no fuel cost, making it virtually inflation free;
8. the cost of tidal energy can be expected to remain relatively stable throughout plant life, whereas costs of thermal energy can be expected to increase with the passage of time;

As a result of the foregoing basic advantages of Fundy tidal power and the results of feasibility studies, the following specific advantages to the Maritime provinces become manifest:

9. the Maritime provinces would receive a reduction in system generation costs over the life of a tidal power project (50-80 years) compared with system cost which would not include tidal power;

10. the Maritime provinces would have some measure of security against unforeseen escalation of generation costs;

11. the Maritime provinces including the northeastern United States, would be subjected to lower environmental pollution loading compared to generation expansion programs without tidal power.

II - EXISTING TIDAL ELECTRIC PLANTS

During the past four decades, there have been a number of major advances in technology, notably in hydraulic turbo-generating units, marine construction and in the mathematical understanding of tidal cycle variations. It is now clear that the major technological problems formerly associated with large-scale tidal power developments have been resolved.

It has only been since the 1960's that the construction of modern tidal electric stations has been attempted. On November 26, 1966, the first large-scale modern tidal electric plant went into operation in the Rance estuary near St. Malo, France. Less than a year later, the plant was fully machined with 24-10,000 kW turbo-generators and has been operating successfully since that time as an integral part of the electrical utility system of Electricité de France (Cotillon, 1979).

During the latter part of 1968, an experimental tidal power plant commenced operation at the mouth of the Kislaya Gulf near Murmansk, U.S.S.R., on the coast of the Barents Sea. The plant was initially equipped with one turbo-generator of 400 kW capacity and its purpose is to provide information on problems that would be encountered with large developments to harness the enormous tidal potential along the White Sea coast of the U.S.S.R. (Bernshtein, 1972).

In August 1984, the first hydroelectric plant in the Americas to use tidal heads as a source of energy, was commissioned. Its main purpose is to demonstrate the operation of a large diameter, straight-flow turbine of Straflo design. The Straflo turbine is installed in a powerhouse constructed in an existing barrage across the Annapolis River at Annapolis Royal, Nova Scotia. The turbine has a diameter of 7.6 m and a rated capacity of 20 MW. The station operates as a single-basin, single-effect tidal plant whose output feeds directly into the utility system of the Nova Scotia Power Corporation (Douma, 1984). This installation, considered a pilot plant to bring out any difficulties which could be resolved for a much larger installation, has been operating successfully. Data will continue to be collected on its operation, including output and production performance, availability and maintenance records, cavitation, rotor deflection, seal wear and corrosion performance (DeLory, 1986).

A description of these existing developments is given in Appendix B.

Morever, within the past two decades, the micro tidal-electric power plant has been making a comeback - in China, at least. In the 1970's there were six tidal plants with 19 turbines, aggregating more than 1900 kW, installed successively in Zheijiang, Jiangsu and Shandong provinces. The maximum ranges at the sites vary from 3.5 m to 7.8 m and the installed unit capacities range between 75 kW and 160 kW (Zhu, 1980).

III - RECENT TIDAL POWER INVESTIGATIONS WORLDWIDE

There are relatively few locations in the world where the tidal range is large enough to justify consideration of tidal power development. In addition to a sufficiently high tidal range, at least five metres as a rule-of-thumb for construction of an economically feasible plant, the site should also include a natural bay with an adequate area and volume and be so situated that the operation of a plant will not significantly reduce the tidal range.

Since the early part of this century, serious, and sometimes quite elaborate, schemes have been advanced for the exploitation of the tidal energy at potential sites, particularly in an attempt to overcome the discontinuity of output. The overall level of interest in tidal power has fluctuated with time as a result of national and international economic and political fortunes. At present, the interest in renewable energy resources, and specifically in tidal energy, is on the flood, particularly stimulated by world uncertainties over conventional fossil fuel sources and concern over the environmental implications of their consumption.

Location of Potential Sites

The identification and mapping of the more important, large potential tidal power sites is not a straghtforward task. Some sites tend to receive concentrated attention for a short while and then to disappear from the literature for long periods. However, some sites which have undergone intensive scrutiny or study during the last decade, such as on the west coast of South Korea and on the Kimberley coast of Australia, hardly warranted a mention in Bernshtein's (1965) definitive work on tidal power. On the other hand, Bernshtein devoted considerable time to sites in Northern Germany and in the Netherlands which are now seldom, if ever, mentioned. The Severn, Fundy and Passamaquoddy (and/or Cobscook) projects have been perennial model locations in this field of renewable energy sources.

Table 1 presents a selected list of those locations where tidal ranges are considered to be sufficiently large and which possess promising physical characteristics to yield sites where potential tidal power projects have been recently studied or are being considered for detailed study. It doesn't purport to be an exhaustive list and is based on information garnered from a number of publications (e.g. Bernshtein, 1965; Gibrat, 1966; Charlier, 1969; and Wayne, 1977). The locations of these sites are identified in Figure 2.

A review of the results of investigations at some of the sites listed is presented in Appendix D to highlight the variety of features that may be encountered and the particular problems associated with tidal electric developments. Obviously, not all of the sites have been investigated to the same level of detail and proposals for some sites are based on very meagre tidal data and other physical information.

The major shift in attitudes to energy developments during the 1970's and the attractive features of tidal power provided a substantial impetus to the reappraisal of this renewable energy source for use in large, modern electrical utility systems. Because of their currency, the results of the 1986 Korean tidal power and of the 1983-86 Severn tidal power study are highlighted in this section.

Garolim Bay (Korea)

The principal conclusions presented in the 1981 report "Garolim Tidal Power Plant, Feasibility Studies" (SOGREAH, 1981) were that: a technically and economically acceptable development would be feasible; a suitable scale installation would be 24 - 20 MW turbo-generator units;

TABLE 1

Selected Potential Tidal Power Sites

Map Location (see Figure)	Location and/or Name	Country	Estimated Potential Capacity MW	Estimated Average Annual Output GWh	Approximate Mean Tidal Range m
1	La Rance (St. Malo)	France	240	500	8.5
2	Kislaya Guba (Murmansk)	USSR	800	**	3.9
3	Cook Inlet Knik Arm	USA		6,000	11.5
	Turnagain Arm			12,500	11.5
4	Passamaquoddy	USA/Canada	300*	1,843	5.5
	Cobscook	USA	150	500	5.5
5	Minas Basin (B9)	Canada	5,338	13,780	12.3
6	Cumberland Basin (A8)	Canada	1,428	3,307	9.9
7	Shepody Bay (A6)	Canada	1,643	4,533	9.6
8	Severn Estuary	U.K.	7,200	14,400	8.5
9	Solway Firth	U.K.	6,300	9,900	5.6
10	Morecambe Bay	U.K.	2,400	4,500	6.0
11	Iles Chausey (Cotentin Penin.)	France	15,000	50,000	8.0
12	San Jose (Valdez Penin.)	Argentina	6,800	75,000	6.0
13,15	Gulf of Mezen	USSR	157,000	450,000	6.5
16	Lumbov Bay	USSR	100,000	300,000	4.5
14	Penzhinskaya Guba	USSR			6.9
17	Secure Bay	Australia	570	1,650	7.0
18	Walcott Inlet	Australia	1,250	3,940	12.0
19	Assan Bay	Korea	450	1,345	6.1
20	Garolim Bay	Korea	400	836	4.8
21	Gulf of Kutch	India	600	1,610	5.0
22	Gulf of Cambay	India	5,500	11,500	7.0

* Double-basin scheme

** Data not available.

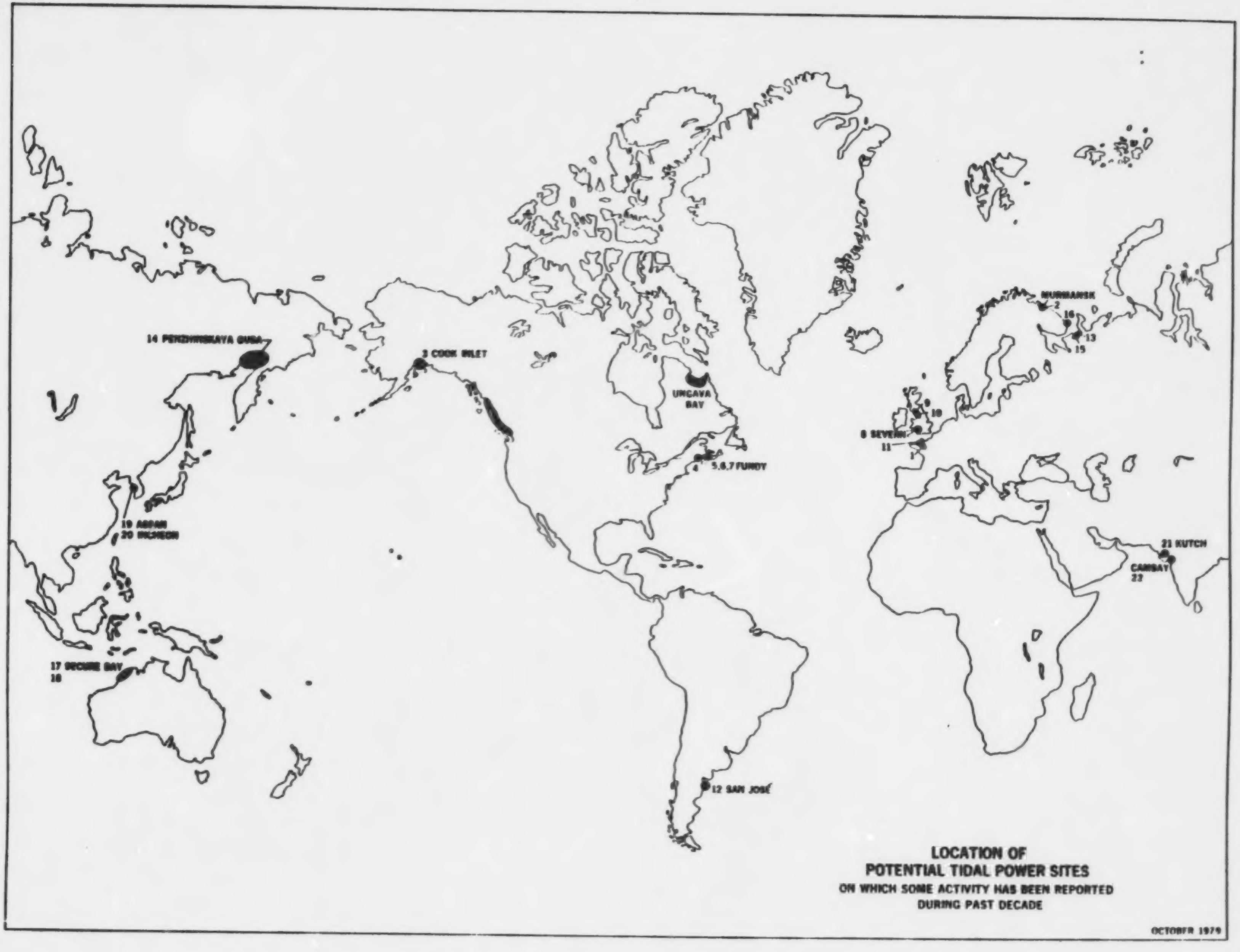

14 PENZHINSKAYA GUBA
3 COOK INLET
19 ASAN
20 INCHEON
17 SECURE BAY
18
UNGAVA BAY
4
5,6,7 FUNDY
MURMANSK
2
16
13
15
9
10
8 SEVERN
11
1
21 KUTCH
CAMBAY
22
12 SAN JOSÉ
LOCATION OF
POTENTIAL TIDAL POWER SITES
ON WHICH SOME ACTIVITY HAS BEEN REPORTED
DURING PAST DECADE
OCTOBER 1979

Figure 2. Location of selected tidal power sites worldwide.

and, such a project could be constructed in about six years at a cost of approximately US$ 633 million (1981 price levels).

Since completion of those studies, appreciable changes occurred in the prospects for electricity generation in Korea. Some of the expansions in capacity which were then in progress or committed proceeded as expected but there was a reduction in the rate of growth of demand so that the program of construction, especially that concerning nuclear plants, has slowed. Also, the dramatic decline in international petroleum prices was another unexpected new development.

The foregoing factors prompted the desire for an update of the 1981 Garolim Bay report as well as a preliminary assessment of the possibility of tidal current power development in Myongyang channel near Usuyong.

The findings of the update study (Kordi, 1986) confirmed the choice and general form and arrangement of the barrage site. However, the conclusion of the study was that, based on current circumstances expectations and economic criteria, the project did not appear attractive.

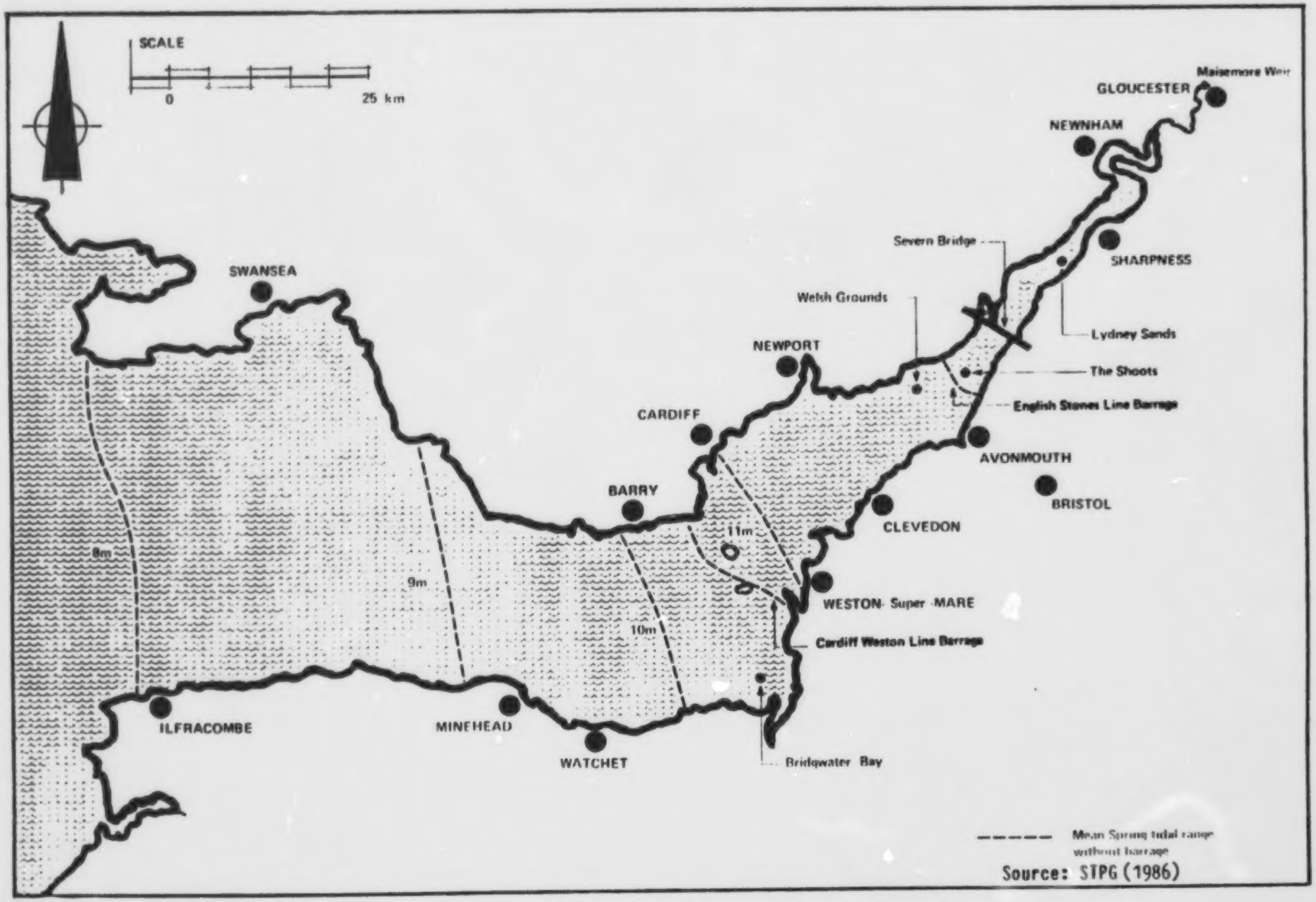
With regard to studies relating to the exploitation of the energy of the tidal currents in Myongyag Channel, the conclusion was rather teneous:

> "Recognizing the limitations of the present pre-feasibility assessment, and of some of the fundamental data and research currently available the indications for tidal current power development at Usuyong are nevertheless distinctly encouraging."

The Severn Estuary

In its report on the most recent and exhaustive study of the Severn Estuary, the Severn Barrage Committee (SBC) in 1981 recommended that the barrage generally aligned between Lavernock Point on the Welsh Shore and Brean Down on the English shore (known as the Cardiff-Weston line, refer Figure 3) should be selected for further concentrated study. The Committee also made a recommendation for a further study of this alignment to confirm acceptability and to establish preliminary design, at an estimated cost of £20M (1981 price levels). The 1981 report presented the results of a study that was carried out at a cost of £2.3M over a period of 2 1/2 years. The foregoing prefeasibility study was started in the fall of 1978 and benefitted from the experiences, techniques and methods of systems analysis developed and modified during the studies of the Fundy Tidal Power Review Board which were reported on in detail in November 1977.

On two occasions, the Chairman of the Management Committee and the Research Director (Energy), ETSU, had discussed and agreed on the advantages of maintaining liaison and exchange of appropriate information in connection with the Fundy and the Severn tidal power studies so as to make the best use, at least cost, of the information collected and/or developed during these studies. This was particularly relevant in view of the rather restricted financial resources that had been made available for the studies. Moreover, the technology applicable to the planning design and construction of a tidal power development was developing rapidly and the pool of expertise directly related to this renewable energy resource is rather limited. Shortly thereafter, in November 1979, officials of the U.K. Atomic Energy Authority and its Energy Technology Support Unit (ETSU) which was managing the study met with the Board's Management Committee in Dorval and were briefed on the results and on the procedures used in the Board's study. In February 1980, at the invitation of the Chairman of the Ad Hoc Working Party on Severn Tidal Power, members of the Management Committee met in London with those responsible for carrying out the civil design, conceptual studies, economic analysis, etc. of the Severn studies. The object of that visit was to exchange views and compare emerging conclusions for tidal power in


SCALE
0
25 km
GLOUCESTER
Maisemore Weir
NEWNHAM
SHARPNESS
Severn Bridge
Lydney Sands
Welsh Grounds
The Shoots
English Stones Line Barrage
NEWPORT
CARDIFF
AVONMOUTH
BRISTOL
CLEVEDON
BARRY
11m
WESTON- Super -MARE
Cardiff Weston Line Barrage
SWANSEA
8m
9m
10m
ILFRACOMBE
MINEHEAD
WATCHET
Bridgwater Bay
Mean Spring tidal range without barrage

Source: STPG (1986)

Figure 3. Location of barrage schemes in the Severn Estuary.

the U.K. and Canada. The liaison and these international exchanges of views were reported to be very worthwhile and the request was made that they continue (Clarke, 1980). Once again, in June 1981, the writer met in London with members of the Severn tidal power study team at the request of ETSU.

The major recommendations of the Severn Barrage Committee may be summarized as follows:

(a) attention be concentrated on the Inner Barrage (Cardiff-Weston alignment) which is the most attractive scheme with the least engineering risk, least adverse effect on man and the environment and the most cost-effective.

(b) the Inner Barrage is likely to be economically attractive if nuclear electricity generation capacity remains limited and it would provide real insurance value against a future in which energy costs are unexpectedly high.

(c) the early initiation of deeper studies to establish the acceptability of the Inner Barrage, including environmental, social and industrial factors coupled with preliminary design and further economic evaluation so that Government would be in the position to decide responsibly, as soon as possible, in the light of all relevant factors, whether to authorize the building of a barrage; such an Acceptability and Preliminary Design Study was estimated to cost no more than £20M over a four-year period.

Following publication of the SBC report, the Severn Tidal Power Group (STPG) was formed, consisting of six member companies (Sir Robert

McAlpine and Sons Limited, Balfour Beatty Limited, GEC Power Engineering Limited, Northern Engineering Industries plc, Taylor Woodrow Construction Limited and Wimpey Major Products Limited) with the aim of giving active support to the Severn Tidal Power Scheme. In June 1983, the STPG was appointed by the Secretary of State for Energy to undertake an Interim Study with the principal aim of assessing "the technical and financial viability of a barrage built and operated by the private sector" in the Cardiff-Weston region.

The objectives agreed upon between the STPG and the Department of Energy for the Interim Study, with the SBC 1981 report as a starting point, were:

- to assess the commercial viability of a barrage, built and operated in the private sector;
- to assess, with others, its environmental effects;
- to obtain an assessment of regional planning implications, in liaison with local authorities and others;
- to define what further work would be required prior to a construction decision, and how such work would be funded.

During the course of the studies, discussions were held with the Central Electricity Generating Board (CEGB) on the integration of the barrage output into the National Grid as well as on possible tariff arrangements and economic and financial aspects.

Based on its two-year study focussing on the foregoing objectives, the STPG (1986) concluded that, in view of the economic and other benefits potentially available, the building of an energy generating barrage on the Cardiff-Weston alignment would be of great value and a permanent asset to the country. The STPG pointed out that, in addition to the economic benefits, there were energy related benefits which would be difficult to quantify:

- strategic diversity of energy sources which has always been public policy;
- a measure of insurance against unpredictable increases in primary energy costs;
- the generation of electricity by tidal power is non-polluting to the environment;
- long operating life of the scheme, perhaps 100 years; the STPG stated that, although the benefit of this long life cannot be easily quantified now for the time at which it arises, its value in 1984 money would be in excess of £500M annually provided that the debt had been fully discharged.

The SPTG confirmed the Severn Barrage Committee's conclusion that the Cardiff-Weston scheme is preferred. The capital cost of this scheme at January 1984 prices would be £5543M and would have an installed capacity of 7200 MW yielding 14.4 TWh. The estimated cost of electricity would be 3.0p/kWh and an internal rate of return of 7.4%. The STPG examined the alternative concept of variable speed DC generation in search of improved economy and flexibility of operation but the gains did not warrant the increase in installed cost. On the basis of the criterion of a 5% real discount rate, which the CEGB recently used in publishing figures for nuclear and coal-fired stations, the STPG calculated the cost of electricity to be the same, i.e. 3.0p/kWh. This may be compared with the published CEGB figures of 2.94p for the Sizewell B PWR and 4.29p for a coal-fired power station. Hence the economics of a Severn Tidal Power Scheme would be comparable with nuclear and cheaper than coal-fired generation electricity. The STGP also concluded that the use of steel caissons is unlikely to show a cost advantage over concrete but a greater use of steel in the internal structure and superstructure may be advantageous and should be examined further.

The STPG's studies also supported the SBC's findings that, in overall terms, there would be an improvement in the harsh environment of the existing estuary. The capability of the estuary to support bird and fish life is unlikely to be decreased and may be enhanced. Moreover, due to the location of the barrage in relation to the main areas of fine sedimentation concentration, no significant sedimentation is expected in the basin. However, the STPG concluded that a considerably smaller scheme, further up the estuary and a few kilometers downstream from the Severn Bridge, which was also investigated at this time, could half fill with sediments in a period whose limits were put at 10 to 100 years, or probably well within the life of the project.

In July 1986, the Secretary of State for Energy announced that the Government was prepared to assist in the financing of further feasibility investigations of the Severn Barrage. The total cost of the next stage of the investigations, to be carried out over the next two years, is expected to amount to £4.26M which will be funded one-third each by the Department of Energy (through the United Kingdom Atomic Energy Authority), the CEGB and the STPG. The work is to be managed by the STPG under the general direction of a Steering Committee on which all three organizations are represented (STPG, 1987).

The overall objective for these Development Project studies, as set by the Department of Energy, are as follows:

1. To reduce uncertainty on the costs and performance of a tidal barrage near to Cardiff and Weston.

2. To examine further the regional and environmental effects of a tidal barrage near to Cardiff and Weston in consultation with all other interested parties.

3. To re-assess the economic viability and financing of a tidal barrage near to Cardiff and Weston in the light of the further studies carried out.

4. To consider further the organizational, procedural, administrative and legal options of a Severn Tidal Power Barrage and to discuss their implications with other interested parties.

5. To define what further work would be required prior to any decision to construct a tidal barrage.

The work programme is formulated to assimilate the important source of information through public consultation. Provision is made to ensure that there are full and proper exchanges throughout the study period in a structured way.

IV - INVESTIGATIONS OF BAY OF FUNDY TIDAL POWER POTENTIAL

Early Inquiries

Interest in the exceptionally high tides of the upper reaches of the Bay of Fundy has fluctuated since the early part of the century. In 1919, Dr. W.R. Turnbull, a noted engineer from New Brunswick, addressed the Engineering Institute of Canada on the subject of "Proposed Tidal Hydro-Electric Power Development of the Petitcodiac and Memramcook Rivers". In 1915, the Cape Split Development Co. of Nova Scotia carried out investigations into exploiting the energy available in Minas passage. In 1928, the Petitcodiac Tidal Power Co. was formed in Moncton to develop a site on the Petitcodiac River and made several representations to government bodies for assistance; nothing came of the proposal.

However, investigations of varying scope and intensity have only been carried out since the mid-1940's. The first major study of tidal power possibilities in the upper reaches of the Bay of Fundy was undertaken in 1944-45 when the Federal and New Brunswick governments retained H.G. Acres & Co. (1945) to report on the tidal power possibilities at the confluence of the Petitcodiac and Memramcook rivers at the upper end of Shepody Bay. The study concluded that an hydraulically-linked, double-basin scheme using these two estuaries could not be economically justified. Several investigations were carried out during the 1950's and early 1960's in the Chignecto Bay and Minas Basin areas under the sponsorship of federal or provincial governments or private agencies. However, none of these was sufficiently definitive to establish the merits of development although they provided additional essential data. An annotated list of these investigations is provided in Appendix C.

1966-69 Feasibility Study

In the mid-1960's, there was an upsurge of interest in the exploitation of the enormous store of potential, renewable energy available in the Fundy tides. This was motivated by the initiative of the Electricité de France in researching, developing, promoting and implementing the La Rance Tidal Power Plant. The Federal Government and the New Brunswick and Nova Scotia governments were prompted to undertake a joint, three-year study to review the position of tidal power in relation to other energy sources. The governments were aware of two significant factors: (i) large amounts of tidal energy could, if a development were found feasible, be made available for export to the United States; and, (ii) the prospect of large-scale development of tidal power warranted investigation by means of systematic surveys and studies of the physical and economic potential of such development, an objective which could not be met by constrained and limited-scope surveys and studies.

The scope of that investigation embraced studies and surveys of the physical and economic potential of electrical power from the Fundy tides and its transmission to markets in Canada and the United States. It also included an appraisal of ancillary pumped-storage schemes to retime a tidal plant's output as well as an assessment of the effects of the power schemes on other interests, such as fisheries, navigation and transportation and upon the tidal regime of the Bay of Fundy.

Of the 23 sites examined by the Atlantic Tidal Power Programming Board (ATPPB), set up by the August 1966 federal-provincial agreement to carry out and report on the surveys and studies, only three seemed to offer the best possibilities for economic power development. These sites are located at the entrance to Cumberland Basin, at the entrance to Shepody Bay and at the entrance to Cobequid Bay in Minas Basin, Sites A8, A6 and B9 (Figure 4). However, none was found to be competitive with

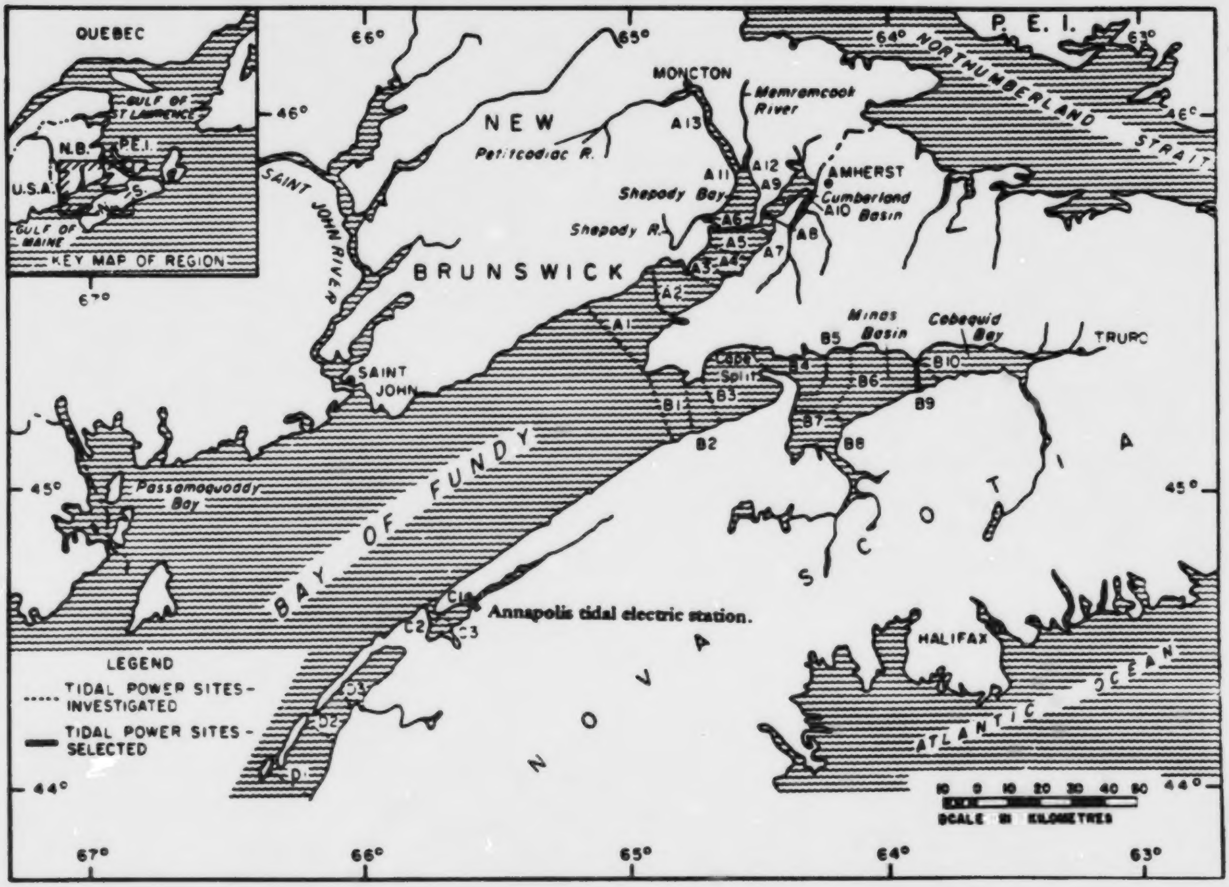

QUEBEC
GULF OF ST LAWRENCE
N.B.
P.E.I.
U.S.A.
N.S.
GULF OF MAINE
KEY MAP OF REGION
P. E. I.
NORTHUMBERLAND STRAIT
MONCTON
Memramcook River
NEW
BRUNSWICK
Petitcodiac R.
SAINT JOHN RIVER
Shepody Bay
Shepody R.
AMHERST
Cumberland Basin
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
A13
SAINT JOHN
Cape Split
Minas Basin
Cobequid Bay
TRURO
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
Passamaquoddy Bay
BAY OF FUNDY
C1
C2
C3
D1
D2
D3
Annapolis tidal electric station.
NOVA SCOTIA
HALIFAX
ATLANTIC OCEAN
LEGEND
TIDAL POWER SITES - INVESTIGATED
TIDAL POWER SITES - SELECTED
10 0 10 20 30 40 50
SCALE IN KILOMETRES
46°
45°
44°
67°
66°
65°
64°
63°

Figure 4. Location of potential tidal power sites in the Bay of Fundy.

the then current cost of energy from alternative sources which derived from a price for oil of only about $2 per barrel. The Board (1969) concluded that "economic development of tidal power is not feasible under prevailing circumstances". Aware of the capital intensive nature of a tidal power project and the significant increase in interest rates during the course of the study, the Board concluded that tidal output could become competitive with energy from conventional sources should the interest rate drop. The Board also concluded that the effects which a tidal power development in the upper reaches of the Bay of Fundy would have on navigation, transportation, fisheries and regional development, would not be such as to alter a decision on the economic merits of the development.

In the light of the bases of these conclusions, the Board recommended "... additional detailed studies be authorized when (a) the interest rate of on money drops sufficiently to suggest the possibility of an economic tidal power development in the Bay of Fundy; (b) a major breakthrough in construction costs or in the cost of generating equipment suggests the possibility of designing an economic tidal power development in the Bay of Fundy; (c) pollution abatement requirements magnify, substantially, the cost of using alternative sources of power; or (d) alternative sources of more economic power supply become exhausted."

Bay of Fundy Tidal Power Review Board

Subsequent to the submission of the ATPPB report on 31 October 1969, there occurred significant changes in energy costs and a greater emphasis on environmental considerations. The Governments of Canada, New Brunswick and Nova Scotia agreed that a reassessment of the economic feasibility of developing power from the tides of the Bay of Fundy should be undertaken, and established the Tidal Power Review Board on 29 February 1972. The Review Board was given the following terms of reference:

1. to identify areas significant to the conclusions of the 1969 report of the Atlantic Tidal Power Programming Board which should be examined in the light of current and projected conditions;

2. to undertake, or recommend procedures for re-examination;

3. to identify and advise on those areas which were not considered in the Progamming Board's report and hence to be an informed source of advice and information in respect of matters concerning the possible development of tidal power; and,

4. to act as a review group to consider and provide advice with respect to any new developments or suggestions of a technical, financial or economic nature which may have a bearing on the tidal power concept.

In responding to the first two terms of its reference, the Review Board reported to governments in September 1974 that, since the economic position of Bay of Fundy tidal power had improved significantly since 1969, additional studies were warranted. The Board set out specific proposals for further, more intensive studies of various aspects of the problems related to development of tidal power in the Bay of Fundy.

The Governments of Canada, New Brunswick and Nova Scotia accepted the Board's recommendations. On 3 December 1975, they signed an agreement which had as its objective the provision of a "firm estimate of the cost of tidal energy in relation to its alternatives on which to base a decision to proceed further with detailed investigations and design". The agreement stipulated that the reports on the studies it had authorized, be submitted no later than two years from its effective date and, as amended on 24 June 1977, within an authorized expenditure of $3.652 million.

In its report submitted under date of 2 December 1977, the Board highlighted four major conclusions:

1. Tidal power, in its most economic role, would displace fossil-fuelled energy production. Although a tidal plant would eliminate some fossil-fuelled generation from the Maritime utilities' expansion programs, it would neither eliminate nor reduce the need for nuclear generation.

2. The reassessment conclusively demonstrated the fundamental economic feasibility of tidal power and the technical and economic feasibility of its integration into the projected generation supply systems of the Maritime Provinces. A probable benefit to cost ratio of 1.2 was indicated for both Site B9 at the mouth of Cobequid Bay in Minas Basin and Site A8 at the mouth of Cumberland Basin.

3. Because the minimum investment would be about $3 billion and because this would result in an inordinate financial burden being placed upon utility customers in the early years, financial feasibility of a tidal power plant would be conditional upon substantial direct participation by governments which would enable raising of the necessary capital and maintaining the cost of service to utility customers at annual levels not exceeding those which would be incurred by an optimal generation expansion program without tidal power.

4. The results of the studies warranted proceeding with detailed engineering, socio-economic and environmental investigations and the financial planning, in the light of the foregoing conclusion, for the development of a tidal power project at the mouth of Cumberland Basin (Site A8).

On the basis of these conclusions, the Review Board then put forward three recommendations to Governments:

1. Detailed investigations for completing definitive designs with detailed specifications be initiated immediately for a single-basin tidal power development at the preferred Site A8, including appropriate ancillary studies to permit an assessment of the feasibility of subsequent, future developments at one or both Sites B9 and A6.

2. Institutional arrangements be established for execution of the detailed investigations and definitive designs and which could also provide the appropriate basis for the development phase.

3. Immediate consideration be given to the resolution of the financial constraints to developing tidal power.

Fundy Tidal Power Update, 1982

By 1981, the Review Board findings, which had been based on estimates using June 1976 prices, had become outdated due to changes in energy prices and policies. In the intervening period, changes had occurred in electrical generating plant and fuel costs, rates of load growth, national energy policies and energy values, all of which had a bearing on the findings and conclusions of the Review Board. Moreover, the possibility of constructing tidal, nuclear or other electrical generation plants explicitly for export of a whole or a portion of their output had not been considered by the Review Board. Indeed, the marketing scenarios, implicit in the Review Board's reassessment gave priority to production of tidal energy for the Maritime Integrated System with export of surplus energy at prices below market value. Such constraints to the sale of surplus energy were not being applied in practice.

The Tidal Power Corporation, a Nova Scotia government agency, believed that the changes had enhanced the economic benefits and financial viability of tidal power. Accordingly, the Corporation undertook, with federal support, to update the economic portions of the Review Board's work. In broad terms, the objective was to answer the question: Is the development of Fundy tidal sites still economically viable under a realistic appraisal of future supply and market conditions?

The studies undertaken by the Update Task Force were confined to Sites A8 and B9, with emphasis on the latter. A new approach to design was prompted by the tremendous impact of the discount rate on projects with long construction periods. The aim was to reduce these costs by the earliest possible closure of the barrage. Caissons were specified to achieve this objective for much of the closure dykes as well as powerhouses and sluiceways. The Review Board had used caissons for sluices and powerhouse only. The result of this approach for Site B9 could advance its closure by 2 1/2 years with the result that the generation of energy during the remainder of the construction period was estimated to be worth at least four times the increase in direct construction costs.

In the report on its investigations, the Update Task Force (1982) pointed out that the Review Board's reassessment and the Update constituted feasibility studies which affirmed that tidal power is economic and that a tidal plant could be constructed in a certain way at a certain cost. However, this did not preclude the possibility that better designs at lower cost may be attainable. In more specific terms, th Update Task Force concluded:

1. Significant reductions in overall cost of a tidal plant can be achieved by shortening the construction period and that should be one of the objectives of definitive design.

2. Under a reasonable marketing strategy, which involves allocating a considerable portion of output to export markets, tidal power is economically viable with a benefit/cost ratio in the 2.4 to 3.0 range, i.e. at least twice the value of the ratio determined by the Review Board. The Task Force noted that the Review Board had found that there would be an objectionable rise in the cost of service of participating utilities in the early years of plant life. Projections made for the Update indicated that the greatly improved benefit/cost ratio would almost completely remove this objectionable feature. The Task Force found that under a wide variety of operating conditions, the capital costs of the project could be recovered in a period of 10 to 20 years after commissioning.

3. Tidal power is financially feasible although raising the necessary capital would be difficult. Appropriate project organization and careful financial planning would be necessary.

4. Because ironclad contracts for the sale of output would be a necessary element in the security required by lenders, long-term, irrevocable export permits would be a necessary condition for project financing.

The Update report noted that no assessment of the environmental impacts of a tidal power plant in the Bay of Fundy has ever been undertaken, although the Review Board had compiled a fairly comprehensive list of concerns. At the request of that Board, draft guidelines had been prepared for an environmental impact statement (Bay of Fundy Tidal Power Environmental Assessment Panel, 1978). The Task Force further noted that, since 1977, research by government agencies, universities and others had added considerably to the data available and to the understanding of natural processes in the aquatic environment. As a result of that work, some of the grounds for concern about sedimentation problems have been removed. That aspect would still require, however, a careful investigation for the purposes of both design and environmental assessment. The Task Force concluded that, although a project at either Site A8 or Site B9 would have environmental impacts - some beneficial and some adverse - the information gathered since 1977 did not appear to invalidate the Board's conclusion that construction and operation of a tidal power plant would be unlikely to produce deleterious effects of prohibitive magnitude. Continuing investigation of environmental aspects would be an essential element in the successful implementation of such a project.

The Update Task Force finally concluded that, if further progress toward the realization of a tidal power development is deemed to be warranted, a precommitment program should be undertaken which would include definitive design, socio-economic and environmental assessment.

The very high cost of a precommitment program, in the order of $50 million, remains an inhibiting factor.

1984-85 Reassessment of a Project at Site A8

Following submission of the Update Task Force report, an expression of private sector interest was received from Alcan Aluminium Limited (Alcan) with respect to a staged program leading to development. The first stage would be to determine whether conditions were sufficiently favourable to warrant undertaking pre-commitment activities. Alcan had tentatively concluded that a project at Site A8 might be the only viable choice for the first commercial Fundy project based on the findings of the Review Board as set out hereinafter under the heading "Preferred Site" and which were deemed to be still valid.

As a result of discussions with concerned parties, including the federal and Nova Scotia governments, agreement was reached to undertake Stage 1: Feasibility Update. This stage was aimed primarily at determining more closely the technical and economic aspects of Site A8 so as to bring its analysis and evaluation up to the previously-established level of a B9 project. Capital costs for a project at Site B9 had been estimated directly from updated designs at 1981 prices while costs for A8 were last estimated directly from Review Board designs at 1976 prices.

The objectives of Stage 1 were stipulated as follows:

1. Determination of optimum design, related energy output and a current estimate of capital costs for selected sites.

2. Selection of a specific project as a development target.

3. Calculation of the generating costs, transmission costs and the amounts and timing of the revenues required to attain financial viability for the selected project.

4. Determination of the commercial viability of tidal energy output in the light of the calculated financial criteria.

The program was completed within two years and the December 1985 report of the Tidal Power Corporation, "Fundy Tidal Power, Stage 1", presents an overview of the activities, results and conclusions of the Study Team. Based on this review, the Tidal Power Corporation concluded, as follows:

1. Further technical work aimed at reducing development costs should be accorded a relatively low priority. Although the technical studies resulted in several design improvements, primarily in the use of variable speed turbo-generators,

the impact on plant cost was relatvely minor. The cost per unit of installed capacity for Sites A8 and B9 is in the lower segment of the range for contemporary hydro plants, suggesting that tidal technology has reached a mature phase.

2. Further work at resolving the marketing, retiming and transmission questions is required before embarking on a pre-commitment program should the supposition in conclusion 3 be negative. The studies did not give a clear indication that tidal power from a project at Site A8 could be marketed or, conversely, that it could not be marketed. It was clear, however, that it would be attractive if the output could be retimed, converting the periodic "slugs" of energy into firm capacity and energy. Transmission access is a necessary condition for sale of tidal energy in New England. Present capacity is now, at times, insufficient to deliver exports from New Brunswick to southern New England. Development of additional capacity for Maritime exports is viewed by some observers as impossible under present circumstances and likely to be possible in the future only with the benefit of broad political and regulatory support. However, a significant block of power and energy would be likely to attract such support.

3. If means of retiming the output of a tidal plant at Site A8 can be established at reasonable cost, pre-commitment studies should be undertaken promptly. The relatively long construction time of seven to eight years for a plant at Site A8 makes any firm judgement either on its usefulness or on the markets open to its output, tenuous at this point in time because current circumstances may change significantly within the next decade. For example, another upswing in oil prices is widely forecast to occur before

the turn of the century. Nevertheless, the retimed output of a plant at Site A8 is likely to be marketable, whereas a market for unretimed output would be less certain.

4. High priority should be given to establishing feasible conditions for development of a plant at Site A8. In particular:

   (i) a concerted interprovincial effort should be made to respond positively to NEPOOL's expressed interest in a substantial power export package from the Maritimes;

   (ii) the ability of Maritime utilities to absorb or partially retime A8 output should be further investigated; and

   (iii) the feasibility of constructing a large retiming facility in the Maritime Provinces should be investigated.

Because of its relatively long construction time, the capital cost of a tidal plant at Site A8 is adversely affected by inflation and concommitant high interest rates during construction. By contrast, after the plant is completed and in operation, it is relatively immune to such factors which, then, merely serve to make tidal energy more attractive. Other things being equal, now would be the best time to undertake a tidal project; after oil prices surge again might be too late.

Study of Retiming A8 Output with a Compressed Air Storage System (CAES)

Previous studies had determined that the greatest economic benefit would be realized from tidal energy through direct absorption of the cyclical output by utility systems. This arrangement is technically feasible providing such energy would constitute only a small fraction of system energy requirements. However, the New England market which now has an annual energy requirement of about 100,000 GWh, is not interested at this time in an unretimed cyclical power supply because of the character of the current regulatory policies in some New England states and also because of the declining real cost of fuel there. Capacity requirements for the late 1990's appear to be the primary concern and NEPOOL, one potential market, indicated an interest in tidal power only if it could contribute to a reduction of its prospective capacity deficit. If retimed tidal energy still proves economic, the resulting firm power would be attractive not only in the northeastern United States but also to the Maritime power systems.

There are several means of retiming but the most cost-effective options would be the coordinated operation with river hydro or CAES. Large river hydro plants with extensive storage capacity would be required to retime the output from the large tidal plants being considered. The Hydro Quebec system includes such facilities but they are relatively remote.

CAES is a developed technology which is highly reliable and cost-effective (EPRI, 1986). It does entail some fuel dependency so that, for each kWh of plant output, it would use 0.75 kWh of electricity and 4000 Btu of fuel. The electricity, obtained from the output of the tidal plant that couldn't be absorbed directly in the market (i.e. retiming of the total energy output would not be required) is used to compress air which would be stored in underground caverns (rock or salt). During times of peak or intermediate electricity demand, the air is released and heated to drive an expansion turbine connected to an electric generator. CAES plants produce three times as much power from a Btu of fuel as conventional combustion turbines since two-thirds of the turbine's power goes toward driving a compressor. Emissions from a CAES plant, for the same reason, are one-third those of a combustion turbine per unit of electricity generated. Preliminary calculations indicate (Baker, 1987) that retimed tidal energy from a plant at Site A8 could displace oil with benefit at a real interest rate of 4% and at Site B9 it could displace coal under most conditions.

In view of the conclusion of the Tidal Power Corporation that "if means of retiming A8 at a reasonable cost can be established, Stage 2 studies should be undertaken promptly", several proposals were received, in February 1987 by Energy, Mines and Resources Canada under its Hydraulic Energy R&D Program, to determine the viability of using a CAES system to retime the energy output from a project at Site A8. It is anticipated that such an investigation will be completed later this year.

Preferred Site

It was concluded by the 1966-69 feasibility study (ATPPB, 1969) and confirmed by the 1976-77 reassessment study (TPRB, 1977) and the update studies of 1981-82 and 1984-85 that the sites offering the best opportunities for economic exploitation of tidal power in the Bay of Fundy, listed in ascending order of the at-site costs of energy, are:

Site B9 at the mouth of Cobequid Bay in Minas Basin
Site A8 at the mouth of Cumberland Basin
Site A6 at the mouth of Shepody Bay.

All of the technical studies have demonstrated that energy could be produced at lower unit cost from B9 than from A8. The first two studies mentioned confirmed that a development at Site A6 was not economic so that the subsequent update studies did not include consideration of that site.

This series of investigations and analyses has brought the design of potential developments to a fairly mature level. The design characteristics produced by the latest study are given by the following tabulation:

	Site A8	Site B9
Barrage length (m)	2,560	8,000
Dyke length	1,340	1,800
Total number of turbines	42	128
Number of spare turbines	3	8
Rated unit output, MW	34	41.7
Installed Capacity, MW	1,428	5,338
Net plant capacity, MW	1,326	5,004
Net annual energy, GWh*	3,307	13,780
Plant cost ($\$10^6$, 1984)**	1,890	5,800
Transmission line cost ($\$10^6$, 1984)***	670	1,200
Total cost ($\$10^6$, 1984)	2,560	7,000

* Delivered at Ludlow, MA.

** The cost figures include all direct construction costs and overheads plus contingencies; they do not include interest during construction nor the value of energy produced during construction.

*** Transmission to Ludlow, MA.

The present design for Fundy plants is based on single-basin, single-effect, ebb-tide generation, with the scale of installation optimized for least unit cost of energy at site. Caissons are utilized to the greatest extent possible for turbines, sluices, temporary sluices to aid in closure and for impermeable sections of the barrage. Dykes would complete those sections of the barrage in the intertidal zone where water depth would be insufficient to float caissons. The designs contemplate the use of Straflo turbines of 7.5 m throat diameter with fixed blades. The units would be regulated by wicket gates and would operate at variable speed with the output transformed and rectified for DC transmission.

The construction method and certain design features have been selected to attain earliest closure of the barrage so that the available installed turbines could commence production. This would occur one year before the last turbine to be installed at Site A8 and about three years before completion of Site B9. Construction time would be eight years after commitment for a plant at Site A8 and 12 years after commitment for B9.

Although the unit costs of output from B9 would be in the range of 60 to 75 per cent of those from A8, depending upon interest and inflation rates, other relevant factors would favour Site A8 as the candidate site for the exploitation of tidal power in the Bay of Fundy:

1. While of substantial size, it would be much smaller than a development at Site B9 and on that basis alone, a more prudent choice for first development since it would be less vulnerable to fears of beginning with an extremely large development.

2. The development of Site A8 would not preclude a development at Site B9 and would provide useful baseline data for a decision regarding the subsequent construction of the much larger development at the latter site.

3. Because of its smaller capital requirements, financing and other associated matters would be less difficult to arrange.

4. Its environmental impact would be significantly less severe, particularly in the sensitive aspect of increasing tidal amplitudes along the New England coast.

5. The A8 site straddles the Nova Scotia-New Brunswick border and because of its interprovincial character would likely attract broader support.

The foregoing confirms the several arguments put forward by the Tidal Power Review Board for the selection of the Cumberland Basin Site (A8) as the preferred site for first development (TPRB, 1977, p.8).

V - ENVIRONMENTAL ASPECTS

The decision to build a tidal electric generating facility must be made with the knowledge that changes will be made to the environment of the region surrounding the estuary and possibly also to areas seaward of the barrage. The basic questions are therefore: How will the facility affect the environment? Beneficially or detrimentally? How can one tell? And what can be done about those effects which are detrimental or will increase the stresses on the indigeneous ecosystems?

Every major technological advance through history has carried with it new obligations to guard against misuse and that is vitally true of tidal electric developments. It is obviously important to be able to predict the biological response to such changes and to assess their ecological significance because, if they are sufficiently important, the predicted ecologial consequences will have to be taken into account in the design, construction and operation of any barrage system. Undoubtedly, as for other types of power stations, some schemes will be more environmentally acceptable than others; moreover, this will not be apparent without the comprehensive studies required for any large or giant project exploiting a renewable resource.

The construction of a barrage which alters the regime of tidal movements will have an immediate and direct effect upon the environment of the intertidal zone and upon the animals and plants that live there. Unfortunately, the existing data base is usually meagre and, initially, considerable subjectivity has to be used to identify the environmental issues. As pointed out by Gordon and Longhurst (1979), impact assessment studies usually have to be concluded simultaneously with, rather than subsequent to, the required basic environmental studies and, as the latter proceed, some of the presently recognized issues may well change, requiring some redirection of the impact assessment studies.

Unique Effects

Many of the effects of a tidal power development are essentially the same as those which would be experienced by construction of any major marine project. Dredge and fill, site access and traffic, and disruptions during construction, all fall into this category. Additionally, however, a tidal electric generating facility will produce unique and important changes stemming from the nature of its operation.

In a state of nature, lands bordering the estuary or controlled basin are alternately inundated and exposed as the tides rise and fall. Closest to the extreme low tide level are lands which only occasionally are exposed and drained. On the other hand, areas extending away from the shores of the estuary may be only rarely submerged during periods of highest high tides. Operation of a tidal power plant designed for ebb-generation would permanently alter this natural condition because: (i) the basin level upstream of a tidal power barrage would normally not fall as low nor rise as high as under natural conditions; and, (ii) the average basin level would be maintained above the mean tide level. A typical basin level hydrograph for Cumberland Basin with an ebb-generation plant operating at Site A8, is illustrated in Figure 5. Mud flats bordering the basin would diminish in extent and marshland vegetation could encroach seaward. The sketch in Figure 6 indicates the position of the new tidal range regime within the basin and the decrease in the intertidal zone. This effect would change the habitat for wildfowl, shore birds and miscellaneous species. The hydraulic characteristics both landward and seaward of the basin would also be altered, such as currents, erosion processes, sediment deposition, and ice formation and movement. Figure 7 summarizes potential interactions between a tidal electric development and elements of the environment.

The impacts of the operation of a tidal electric development may be summarized as:

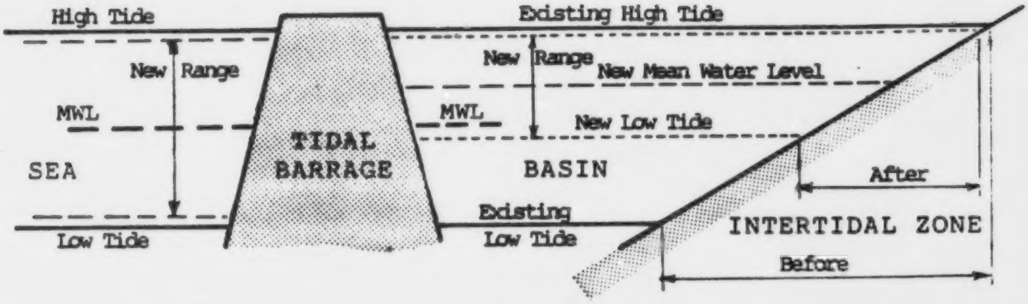

High Tide
Existing High Tide
New Range
New Range
New Mean Water Level
MWL
MWL
New Low Tide
TIDAL BARRAGE
SEA
BASIN
After
Existing Low Tide
Low Tide
INTERTIDAL ZONE
Before

Figure 6. Probable position of tidal range in the tidal basin and effect on intertidal zone for ebb-generation mode.

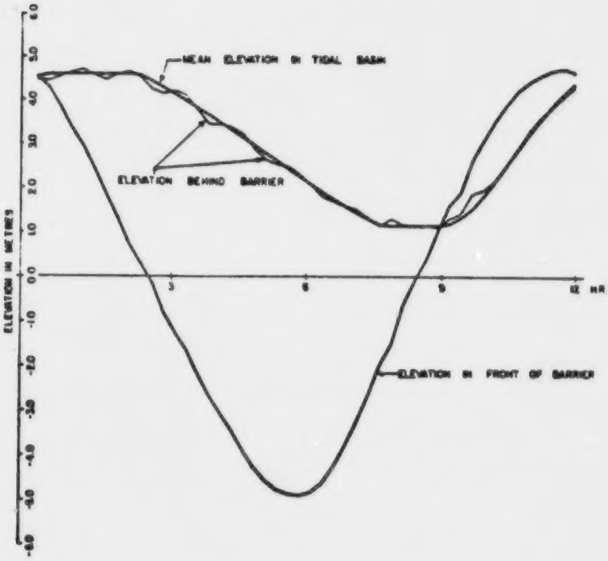


Figure 5. Example of tidal basin water level variations during ebb-generation mode.

TIDAL PLANT FACILITIES AND CONSTRUCTION ACTIVITIES	ELEMENTS OF THE ENVIRONMENT																						
	TOPOGRAPHY/BATHYMETRY	MINERAL RESOURCES	SOIL	DRAINAGE & SURFACE RUNOFF	GROUND WATER	TIDAL REGIME	FRESH/SALT WATER INTERFACE	PHYSICAL OCEANOGRAPHY	SEDIMENTATION/EROSION	WATER CHEMISTRY	AQUATIC ECOSYSTEMS	MIGRATING AQUATIC SPECIES	BENTHIC ECOSYSTEMS	INTERTIDAL ZONE PRODUCTIVITY	WETLAND VEGETATION	WETLAND WILDLIFE HABITAT	UPLAND VEGETATION	UPLAND WILDLIFE HABITAT	CLIMATE	AIR QUALITY	NOISE AND VIBRATION	ICE FORMATION	SURFACE WATER HYDROLOGY
CONSTRUCTION ACTIVITIES																							
SITE DEVELOPMENT - LAND BASED																							
CLEARING, GRADING, SURFACE EXCAVATION, BUILDING STRUCTURES, MATERIAL STORAGE	●		●	●	●				●	●	●				●	●	●	●		●	●		●
ROAD, RAIL SPUR CONSTRUCTION	●		●	●	●				●	●							●	●		●	●		
EXCAVATION FOR ABUTTMENTS	●		●	●	●				●	●				●	●	●	●	●		●	●		
MATERIAL PLACEMENT	●		●	●	●				●	●				●	●	●	●	●		●	●		
OPERATE LAND BASED MARINE EQUIPMENT	●		●	●	●			●			●		●	●	●	●	●	●			●	●	
WORKER FACILITIES AND USE	●		●	●	●					●						●	●	●					
SITE DEVELOPMENT - MARINE																							
PILE DRIVING	●		●					●	●		●	●	●	●	●	●		●			●	●	
INTERTIDAL CONSTRUCTION ZONE	●		●	●				●	●	●	●	●	●	●	●	●	●	●		●	●	●	
DREDGING	●		●					●	●	●	●	●	●	●	●	●					●	●	
MATTRESS/DIKE PLACEMENT	●		●					●	●	●	●	●	●	●	●	●					●		
TUG AND BARGE OPERATION	●									●	●	●								●	●	●	
CAISSON STORAGE AND TRANSPORT	●							●	●		●	●	●	●							●	●	
CAISSON INSTALLATION	●							●	●		●	●	●								●	●	
STATIONARY MARINE EQUIPMENT	●							●	●	●	●	●	●	●							●	●	
MECHANICAL/ELECTRICAL EQUIPMENT INSTALLATION																				●	●		
SITE ACCESSIBILITY																							
ROAD, RAIL TRANSPORT OF PERSONNEL, MATERIALS, OR EQUIPMENT			●														●	●		●	●		
MARINE TRANSPORT OF PERSONNEL, MATERIALS, OR EQUIPMENT								●		●	●			●	●	●					●	●	
REMOTE CONSTRUCTION FACILITIES																							
CONSTRUCTION MATERIAL SOURCE AREAS	●	●	●	●	●												●	●		●	●		
DREDGE DISPOSAL SITES - UPLAND	●		●	●	●												●	●		●	●		
DREDGE DISPOSAL SITES - MARINE	●							●	●	●	●	●	●	●									
OPERATION OF PERMANENT FACILITIES																							
ACCESS AND CLOSURE DIKE (PRESENCE)	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				●	●
PHYSICAL ESTUARY BARRIER	●				●	●	●	●	●	●	●	●	●	●	●	●			●			●	●
POWERHOUSE AND SLUICEWAY (PRESENCE)						●	●	●				●	●									●	
TURBINE OPERATION						●	●	●	●	●		●									●	●	●
SLUICEWAY OPERATION	●					●	●	●	●	●		●									●	●	●
POWER FACILITIES (PRESENCE)	●			●													●	●				●	
SWITCHYARD OPERATION																					●		
DRYDOCK AND DOCK FACILITIES (PRESENCE)	●			●					●	●	●		●	●	●	●						●	
LONG-TERM OPERATION										●	●			●		●			●		●	●	
IMPOUNDMENT (PRESENCE)	●			●	●	●	●	●	●	●	●	●	●	●	●	●			●			●	●
WATER LEVEL FLUCTUATION	●		●	●	●	●	●	●	●	●			●	●	●	●			●			●	●
LOCKS (PRESENCE)													●									●	
OPERATION								●	●			●	●								●	●	
SITE ACCESS (PRESENCE)	●			●										●	●	●	●	●					●
ROAD, RAIL SPUR USE																	●	●		●	●		
MARINE USE								●		●	●			●	●	●				●	●	●	
WORKER FACILITIES (PRESENCE)	●			●								●					●	●					
USE OF WORKERS					●							●									●		

● indicates potential for interaction between environmental element and plant component

Source: Acres American (1981).

Figure 7. Potential interaction between a tidal plant and elements of the environment.

(i) Causes - changes in water levels, water flow patterns and velocities and sedimentation patterns; physical presence of the barrage;

(ii) Impacts on Man - agriculture, land drainage and flooding, water quality, opportunity for estuary crossing, employment, industry, amenity, recreational opportunities, ports and navigation and shore protection;

(iii) Impacts on the Environment - birds, migratory and pelagic fish, aquatic mammals marginal wetlands, the estuarine ecosystem balance, geological sites.

The foregoing are not necessarily listed in order of importance since these impacts will have different values and influences in different estuaries. Most of the potential impacts arise from the altered tidal regime, i.e. the range and pattern of water level fluctuations and the properties of tidal currents, and would, therefore, generally be felt in relatively close proximity to the site. However, depending upon the scale of the development, its position relative to resonance, etc., the tidal regime on coast lines relatively remote from the development could be affected; for example, although the effect of operation of a tidal electric plant at the mouth of Cumberland Basin (Site A8) would have no measurable effect at Boston, Massachusetts, about 650 km south along the Atlantic coast, the larger development in Minas Basin would likely increase the range of the mean tide at Boston by about 24 cm.

Indirectly affected would be wave climate, temperature and salinity characteristics, stratification, density currents and ice formation. With regard to fresh water, both ground and surface water processes could be affected, such as flooding, draining of marsh lands and salt water intrusion. Changes in the foregoing characteristics could influence the climate, water quality, geological characteristics and plants and animals.

Tidal Regime

Subsequent to the pre-feasibility study of 1966-69, an on-going interest in the Fundy tidal phenomenon led to the belief that the entire Bay of Fundy/Gulf of Maine system, out to the continental shelf, represents a single resonant system with a periodicity close to that of the semi-diurnal tide. Accordingly, under the sponsorship of the Ocean and Aquatic Sciences Services of Environment Canada, Greenberg (1975) developed a finite difference model covering this much larger area. Recognizing the basic requirement for an accurate simulation of the exceptional tidal ranges of the Bay of Fundy for its reassessment studies, the Review Board established an Advisory Panel composed of leading specialists worldwide in the field of hydrodynamic regime modelling to review all available options and recommend a course of action. On the basis of the Panel's advice, the Board proceeded with its program of regime analysis using the "Greenberg" broader based, mathematical model and also initiated offshore tidal gauging and improvement of the inshore data base to support its analysis of regime conditions.

As reported by the Review Board (1977), the Greenberg hydrodynamic numerical model predicted increases in tidal amplitude at Boston of about 15 cm for a plant at Site B9 and about 3 cm for a plant at Site A8. These predictions were made for the M2 (lunar semi-diurnal or mean) tide and are not necessarily correct for all actual tides which are made up of many other constituents in addition to the M2 constituent. Moreover, the 1981-82 study had resulted in changes to the configuration of the plants proposed for Sites A8 and B9 which would be capable of affecting the tides. Accordingly, the 1984-85 studies incorporated an update of the Greenberg model (DeWolfe, 1985) to determine the effects of such changes and, if possible, to provide more accurate predictions based on actual tides over a lunar month. In summary, the results clearly showed that the effects on the tidal regime by operating a plant at Site A8 would not be of a magnitude to produce detectable impacts in the lower Fundy/Gulf of Maine region. The operation of a plant at B9 would induce small changes in amplitude of the tides at Boston of about 12 cm.

In the wake of the 1976-77 reassessment studies, the hybrid modelling technique was successfully applied to the Bay of Fundy (Funke, 1981), specifically for a tidal electric plant operating at Site A8. This technique will prove invaluable in the construction phase and in verifying operational procedures. Moreover, under the Hydraulic Energy R&D program of Energy, Mines and Resources Canada, ASA Consulting Ltd. of Dartmouth and Discovery Consultants Ltd. of Wolfeville have very recently developed (Margerie and De Wolfe, 1987) a 3-D hydrodynamic model for describing detailed tidal and current patterns in Cumberland Basin for both the natural regime and a regime modified by the operation of a tidal plant at Site A8. This model will provide the best basis for impact studies of the effects of plant operational regimes on the ecosystem, sediment and morphological regimes of Cumberland Basin as well as to study the effects on turbidity distribution and benthic and pelagic organisms.

With an accurate knowledge of the magnitude and regime of the physical changes, it is possible to assess the effects of such changes on human activities and other physical features and on the biology of the system. As with most natural ecosystems, predictions of impact on biological phenomena are more generalized and less precise than with physical ones. This results, in part, from the ability of natural communities to adjust to changes in the physical regime and partly because knowledge of biological processes is usually much less complete.

Development of a Data Base

The various impacts and their causes are to a large extent inter-related and involve many complex issues. An estuary would be truly unique if sufficient information already existed to enable evaluations to be made of the environmental alteration, the effects on natural processes and the natural resource availability. A major environmental field data collection and analysis program is necessary in order to define environmental impacts with some degree of precision although, in the field of environmental evaluations, there will always remain a number of uncertainties. In fact, the conclusions reached on environmental impact will inevitably be less certain than those reached on technical feasibility or on economic feasibility. Moreover, it may not be possible, nor indeed desirable, to quantify some impacts in economic terms.

In fulfilling its terms of reference, the Atlantic Tidal Power Programming Board developed a very broad assessment of the effects of its selected tidal power schemes on other socio-economic interests, such as fisheries, navigation and transportation, based on the relevant data then available, which was meagre or non-existent.

As already noted, the Bay of Fundy Tidal Power Review Board concluded in 1974 that the economic position of Fundy tidal power had improved significantly and, moreover, that any further intensive engineering and economic studies must embrace the environmental aspects of such projects. In its report to governments in 1974, the Review Board recommended a series of phased studies to be undertaken on a comprehensive basis, particularly with respect to, *inter alia*, "environmental impact". Therefore, the aim of the Board with respect to the environmental aspects of its 1976-77 reassessment study was: (i) the identification of all environmental concerns related to resources use and availability, to the fullest extent possible; (ii) the collation of relevant completed and continuing studies; (iii) ensuring that environmental concerns, either quantitatively or qualitatively, with respect to candidate sites were taken into acount in its reassessment report (estimates of the worst and best limits of impacts were to be quantified, where possible, from available information); and, (iv) the preparation of a detailed program of investigation for consideration in any further program of studies.

The Board engaged consultants to identify environmental concerns and to provide a review of the significance of the issues as perceived and to prepare a detailed study program. The Board also sponsored a Workshop on the Environmental Implications of Fundy Tidal Power (Daborn, 1978) and requested the appropriate authorities to develop guidelines for the preparation of a formal environmental impact statement which would be an integral part of a pre-investment stage (Tidal Power Environmental Assessment Panel, 1978). Acknowledged experts in the various fields of environmental concern were consulted and a provisional assessment of the potential significance of each aspect developed.

It was very evident from the Workshop of 1976 that research on the biological aspects of the Bay of Fundy had been very sporadic. The available knowledge, at that time, of the biological processes and parameters diminished steadily as one proceeded up the Bay and was virtually non-existent with respect to the headwater basins. In his report to the Board on an overview assessment of a draft synthesis report on environmental implications of tidal power development in the upper Bay of Fundy, Longhurst (1977) of the Institute for Marine Environmental Research, Plymouth, England, concluded that "... the lack of solid information concerning the physics and biology of the Fundy region was sufficiently serious that there was much unjustified erection of hypotheses in several of the documents." Dr. Longhurst went on to say:

> "Both from my reading and from the site visits I have been very struck by the similarity between the Bay of Fundy and the Severn Estuary-Bristol Channel system in England, and I believe that much of the ecology of the two areas is simply an extreme expression of what is normal in estuaries with large tidal ranges and hence strong tidal streams. The turbidity regime of the water in the upper basins of the Fundy is very similar to that in the Severn, and the wide exposed mud flats not only look very similar but contain an almost identical fauna (the Macoma baltica community) of benthic animals which form the food of particularly large concentrations of shore birds. The major concerns about the consequences of a barrage are similar in the two regions and relate primarily to water levels on both sides of the barrage, and the possible effects of sediment accumulation after closure."
>
> "To an environmentalist the striking difference between the two regions is the relative amount of information available. While the Severn has been studied in great depth in recent years, with the expenditure of about 20 man-years per year from one Institute alone, so that numerical simulation models are now available for many of the ecological processes, the upper Bay of Fundy appears not to have been studied except in a fragmented manner, and at a much lower level of effort. This, of course, has certain implications about the expressions of concern about ecological effects of a barrage in Fundy and suggests to me the desirability (from a Fundian point of view) of investigating the extent to which conclusions and ecological studies performed in the Severn and other similar environments can be usefully transferred to Fundy."
>
> "In the short term, I suggest that much more use be made of short-cut methods by the transference of assumptions arrived at by research elsewhere to the Fundy situation; I suggest two examples, ... including the re-making of the holistic GEMBASE model into what might come to be called GEMFUND."

Based upon its preliminary review of such infomration as exists and advice from federal and provincial environmental authorities, as well as a broad spectrum of other scientific sources, the Review Board concluded that there were not any apparent major environmental or social problems which would prohibit development at any of the selected sites.

Fortunately, more attention by research institutes was subsequently focused on developing basic environmental study programs for estuaries, particularly those which appear to offer some promise for energy exploitation. Several workshops, seminars and symposia have also been organized within the past decade to exchange information and advance the debate on estuary mangement (Severn, Dineley and Hawker, 1979). Shaw (1980) edited about 18 articles on environmental factors with reference to the Severn Estuary (see also Severn Barrage Committee, 1981, Vol.II, Chapt. 14). A useful bibliography (now a decade out of date), primarily related to environmental aspects of the Bay of Fundy, was compiled by Moyse (1978). Daborn (1985) has drawn attention to the enormous strides that have been made during the past decade in the understanding of the natural systems in the Bay of Fundy. The large scale coordinated program of research by scientists and engineers in Atlantic Canada, coordinated by an *ad hoc* body, the Fundy Environmental Studies Committee of the Atlantic Provinces Council on the Sciences, has provided the basis for the resolution of many of the impacts that had been identified as problems.

In a paper entitled "Environmental Impacts of a Large-Scale Tidal Power Development in the Bay of Fundy", soon to be published, Baker presents a straightforward and factual summary of probable impacts, together with rough estimates of their magnitude, based on the now substantial body of information that has been published in the form of reports, papers and proceedings. Baker readily points out that the estimates are not necessarily of the type which might be made by an environmental professional but rather that they reflect the viewpoint of a potential developer who, before investing further development effort, needs to gauge the risks involved and the probablility that development will be feasible. Baker concludes that there are only two impacts that could be potential project-stoppers: fish mortality (especially with reference to shad) and the effect of increased tides on the New England shoreline. With reference to fish mortality, he suggests that it will be necessary to identify effective means for excluding all or most fish from turbines before any further progress toward development is attempted. With regard to coastal impacts, there would be no problem for a plant operating at Site A8; for a plant at Site B9, such impacts could be minimized by maximizing installed capacity. Other negative impacts would require remedial actions, where possible, and the costs of such actions would have to be internalized in capital cost projections.

In making an environmental assessment, a tidal electric generating facility should be considered as only one prospective component of the future generation mix of the regional utility system. Thus, the assessment of environmental implications of a tidal project should be placed in perspective through comparison of system impacts, with an without a tidal electric generating facility (Waller, 1972). In so doing, judgements of non-quantifiable aspects, such as the reduction of acid-forming gases and other pollutants, may be approached on a comparative basis and lead to a better appreciation of the relative importance of potential impacts, both beneficial and adverse.

At a recent workshop sponsored by the Electric Power Research Institute in the United States, experts in the field of turbine engineering and biologists working on assessing turbine fish passage problems considered this subject in depth. Two important conclusions arose from that workshop: the need to redress the lack of studies of fish passage through bulb and tube-type turbines; and, the lack of information about cluepids (shad, alewives and herring) compared to that available for salmonids (salmon and trout). Much of the earlier research, viz. during the 1950's and 1960's was conducted on Francis and Kaplan turbines and involved tests with Pacific and Atlantic salmon and steelhead trout. Based on observations on the effect of fish passing through the turbine at the Annapolis Tidal Generating Station in 1985, it became evident that study was required with respect to the apparent difference in vulnerability of those species compared with shad, alewife and herring. Beginning in 1986, Energy, Mines and Resources Canada sponsored a research proposal: to document fish passage mortality in tube-type turbines; to compare fish mortality of cluepids and salmonids; and, to help identify reasons for the unexpected fish mortality at the Annapolis plant. The research is being carried out at a small tube-turbine installation at the outlet of Fourth Lake on the Sissiboo River, Nova Scotia, where the flows are small enough to allow for the total recapture of all test and control fish. The report on the tests and analysis is scheduled for submission in early 1988. Of significance, also, will be the results of studies commissioned by the Tidal Power Corporation and the Nova Scotia Power Corporation aimed at testing behavioural diversion techniques, i.e. to induce fish to use fish passages instead of turbine passages. These studies are underway and are scheduled for completion this year.

VI - THE NEXT STEP

The investigations of 1966-69, 1976-77, 1981-82 and 1984-85 have: (i) provided an in-depth background to the potential for tidal power development in the Bay of Fundy; (ii) identified the most appropriate sites for development; (iii) defined technically sound designs and construction methods; and (iv) showed that a tidal power development will provide net economic benefits.

It is also clear from the studies carried out over the past two decades that not only are there now available proven and mature technologies for the exploitation of the energy of the Fundy tides, but also such exploitation would be competitive to conventional sources of electrical energy in the Maritime provinces as well as in the New England states. Furthermore, it is quite evident that the retimed output from a plant at Site A8 is likely to be marketable whether or not there is another upswing in oil prices in the next decade. The results of the preliminary investigation into the retiming of a part of the output from a plant at Site A8 will be available later this year. Also, the results of the tube-turbine fish passage research will be available in early 1988.

In view of the findings of the most recent study, it would be prudent to proceed immediately to define the ways in which the studies can be progressed in a logical manner. A plan should be prepared to define the scope of the further work required prior to a construction decision, the framework and scheduling for that work and the funding required. Such a plan would establish the program of activities leading up to a commitment to construction. The activities would relate to such matters as, *inter alia*: further definition of the project scope with studies to refine, validate or amend the present engineering concepts; planning of appropriate environmental and regional studies, including the preparation of preliminary employment, regional economic and environmental assessments; consultation with interested parties, as an iterative process, to further define the requirements of local interests so as to secure the effective development, construction and operation of the project; definition of institutional and regulatory requirements; transmission access; development of a financial scheme and sourcing of funds; and, tentative marketing agreements. Without such a plan, it is difficult to see how, through an ad hoc approach to studies on different aspects subjectively selected by various investigators and interests, proper data and information can effectively be made available to support a construction commitment decision. The preparation of such a plan would likely require four to six months and cost in the order of $400,000.

Consideration should also be given at this time to the Draft Guidelines for the preparation of an environmental impact statement which were developed by the Bay of Fundy Tidal Power Environmental Assessment Panel in 1978 to reflect the requirements of the environmental impact policies and procedures of the Governments of Canada, New Brunswick and Nova Scotia. The guidelines are intended to define for a proponent, the scope, orientation and general format of an Environmental Impact Statement (EIS) and at the same time provide guidance on the particular concerns or issues that should be addressed. In the introduction to the draft guidelines, the Panel states:

> "Given the possible wide ranging consequences of a project of this magnitude, the guidelines stipulate that the EIS must forecast effects or changes within the social/community sphere as well as the natural or non-human environment. Within this expanded concept of the environment, the guidelines are invited to specifically orientate the EIS toward the identification of likely changes in existing patterns of resource uses, functions and potentials. In order to identify and predict the direction and magnitude of these changes, an understanding of the natural and human resources of the region influenced by the project will be obtained and presented."

In initiating further activities aimed at the development of tidal power at Site A8, the governments concerned should not overlook their Bay of Fundy Tidal Power Review Board which they established in 1972. In addition to specific requests with regard to the Atlantic Tidal Power Programming Board study and the general direction of the reassessment study, which have long since been fulfilled, the Review Board was also requested:

> "to act as a review group to consider and provide advice with respect to any new developments or suggestions of a technical, financial or economic nature which may have a bearing on the tidal power concept".

Thus, the current status of tidal power and the 1985 report of the Tidal Power Corporation, in particular, should be reviewed by the Board with specific reference to those conclusions relating to the financing of a capital intensive project.

Advantage might also be taken of the continuing and deepening interest in harnessing the energy of the Severn Estuary exhibited by the initiation of the current studies. There would be considerable merit, in view of the background on the Severn and Fundy estuaries, in re-establishing immediately a more formal liaison with ETSU and the Steering Committee of the newly initiated £4.26M Development Project. The information exchange at the completion of the Review Board's study proved beneficial to the tasks of the Severn Barrage Committee. Similar benefits to both the Fundy and Severn studies would undoubtedly be forthcoming through a re-establishment of such exchanges of information and views. It may be of interest to note that, in acknowledging a meeting of representatives of the two study groups in London in February 1980, Dr. F.J.P. Clarke, Chairman, Ad Hoc Working Party for the Severn Barrage Studies, stated:

> "One other tentative suggestion which was made and appealed considerably to Roger Price [Tidal Power Programming Manager, ETSU] was that, since the nominal time scale of the first Fundy scheme is earlier than that for the Severn, we might make use of your Cumberland Basin Scheme for our prototype trials on larger turbines. Although this is very speculative at this stage, it is a possibility that we would like to consider nearer the time."

It was subsequently decided that it would not be economic to use larger bulb turbines than had been previously been built, which had prompted the idea of prototype trials for such turbines. However, the concept of using the Cumberland Basin scheme (1400 MW) as a logical stepping stone from the size of the La Rance plant of 240 MW to that of the Severn Barrage scheme (7200 MW) might be worth exploring further. Now would be the logical time to consider such a concept in view of the progressing studies on the Severn Estuary.

A tidal power development could be a major regional asset in the Maritime energy picture with a useful life in excess of 100 years, with no fuel cost, a significant hedge against inflation of energy costs, no environmental pollution loading and reduced energy costs over the longer term.

APPENDIX A

TIDAL SCHEMES AND MODES OF OPERATION

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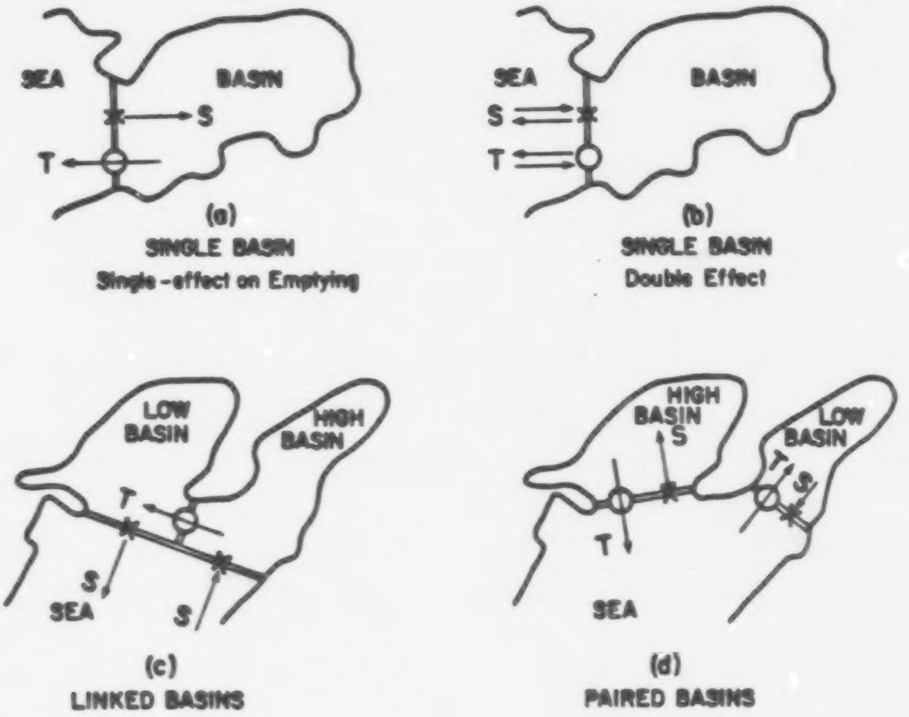
TIDAL SCHEMES AND MODES OF OPERATION

Single-basin Development, Single-effect Mode of Operation

The simplest engineering solution to the recovery of tidal energy and its conversion to electricity would be to build a barrier across an estuary and equip it with turbines and with sluices and allow the basin thus formed to fill on the rising tide. At high tide, the sluice gates would be closed and the ebbing water would give rise to a head - a relatively small one - between its own level and that of the water of the basin. If the basin were emptied through hydraulic turbines, energy of the tidal water would be retrieved. This is the simple tidal mill concept.

Such a scheme, illustrated diagrammatically by Figure A-1(a), is known as a "single-basin" development using "single-effect" turbines, or turbo-generators. As their name implies, single-effect generating units are designed to operate or generate power in one direction only. A sluiceway section, normally comprising a fairly large number of sluices, serves to fill the basin on the flood tide. In addition to the powerhouse and sluiceway sections, the dam or barrage is completed by a section of dyke which effects the closure of the estuary.

Ebb generation: The scheme would be operated as follows (refer Figure A-2): at or shortly after the point of high tide when the basin is filled, the filling sluices are closed. After a waiting period, during which the water level in the ocean begins to fall, generation is started at a point in time where the head on the turbines has reached approximately half the value of the tidal range, i.e. with the ocean water level at approximately mean sea level. Operation proceeds with the flow from the basin to the ocean, past the point of low tide, until the head on the turbines has reached the minimum value under which the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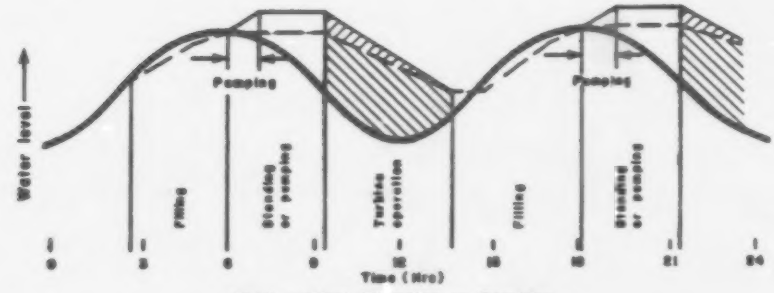
(a)
SINGLE BASIN
Single-effect on Emptying

(b)
SINGLE BASIN
Double Effect

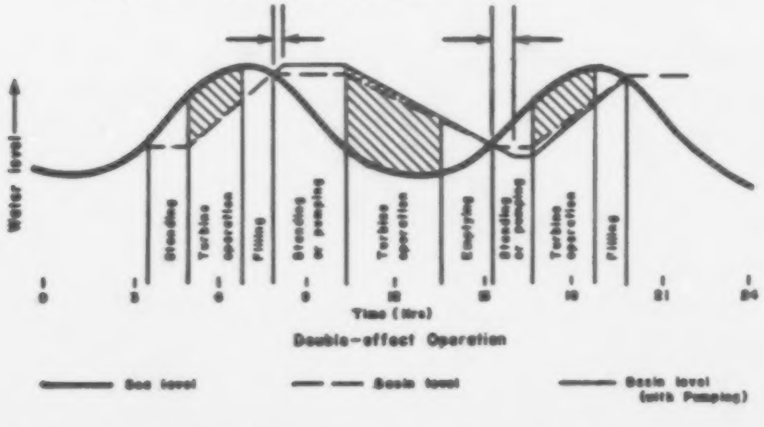
(c)
LINKED BASINS

(d)
PAIRED BASINS

Figure A-1. Some Concepts of Development.



Single-effect Operation on Emptying



Double-effect Operation

Figure A-2. Water Level vs Time for Ebb and Two-way Generation turbines are capable of developing power. At this point, the distributor gates to the turbines are closed and, after a short waiting period, the ocean level rises to what is now the basin level. When the two levels become equal, the sluice gates are opened and the basin is permitted to fill with the rising tide. This is termed "ebb generation".

Flood generation: By turning the powerhouse around so that its water inlet is on the sea side and its outlet on the basin side, energy can also be developed as the tide is rising and the basin is being filled - also a "single-effect" operation, but termed "flood generation". However, a flood-generation scheme would provide less energy than the equivalent ebb-generation scheme. The primary reason for this is that the area of the basin or estuary decreases with depth giving rise to the following results: (i) the water levels in the basin would rise at a faster rate in the early stages of flood generation than they would fall during the same period under ebb generation; and, (ii) the volume of water that could pass through the turbines would be less for a flood-generation scheme than an equivalent-sized, ebb-generation scheme. Thus, generation on the ebb tide takes full advantage of the greater volume (and higher head) in the upper levels of the basin.

Single-basin Development, Double-effect Mode of Operation

With turbine technology now available, it is possible to use the same set of turbo-generators to produce electrical energy over both the rising and falling tides, i.e. "double-effect" turbines could be installed, although at an increased cost because of the more complex equipment. Such units are capable of generating, as well as pumping, in both directions and also to work as orifices in both directions, i.e., six modes of operation are possible. The attraction of such two-way generation is that it provides not only for the production of electricity during a greater portion of the solar day than single-effect, but it also permits greater operational flexibility.

Referring to the point in the operating cycle of a single-effect scheme where the turbines have just reached their lowest head under which they can generate (Figure A-2), the runner blades would be "feathered" so that the units would operate as orifices to assist the sluices in draining the basin to the level of the sea then prevailing. At this point, the barrage is closed and, after a subsequent waiting period during which the ocean water level rises above that in the basin, the turbines are started in the generating mode and proceed to generate with the flow from the ocean into the basin. At the end of this generating cycle, the basin is filled and an ebb-tide generating mode follows.

However, towards the end of both the ebb and flood generation periods, the sluices must be opened sooner in order to reduce the basin level quickly to provide for the period of flood generation or to fill the basin as quickly as possible prior to the start of ebb operation. Thus, for any given number of turbines and sluices, slightly less energy would normally be produced by two-way or double-effect generation than by single-effect or ebb-generation only. Under the former mode of operation, the operating heads are generally lower than for single-effect operation. On the other hand, the increased heads developed under higher tidal ranges could be more fully utilized with double-effect operation so that, as the tidal range increases, the latter operation could generate more energy per tide with the same number and size of sluices and turbines. Also, with two-way generation, the turbines would operate somewhat less efficiently at any given head than for single-effect or single-directional flow since optimization for the latter condition must be compromised to obtain an optimum design for double-effect or two-way flow.

Although there would be some capacity credit to an electric utility system from single-effect operation of a tidal electric plant, double-effect operation could offer a considerably greater (2 to 3 times) capacity support to a system because of its greater flexibility and could do so with only a nominal loss in energy production assuming that the plant would only be called upon to operate for capacity infrequently, in the order of 4 to 6 days per year, under a maximum capacity operating mode. It should be noted, however, that the principal limitation on the value of a tidal scheme as a capacity source is its inability to sustain capacity for more that a short time. However, under real system operation, the full capacity potential available from the tidal electric plant might not be required at all times of emergency and a very wide range of operating strategies could be possible.

Considering energy generation only, ebb-generation would undoubtedly yield the minimum unit cost of energy.

Pumping

As already noted, the turbines can be designed to operate in the pumping mode under both single-effect and double-effect operation. The advantage of this capability would theoretically be an energy gain, if the pumping were to take place when the basin and sea levels were nearly the same and the water were used later in the tidal cycle when the head would be greater. The possibility that the energy output could thus be retimed by an hour or two might also be advantageous in the case of single-effect operation since the turbines could be started in the pumping mode at the point in the operation where the basin has just been filled by means of the sluiceways. Thus, under a very low head, the turbines operating in the pumping mode could fill the basin beyond the level of high tide, or "over-fill" it (Figure A-2). In the subsequent operation, the water which has been pumped into the basin under very low heads, could be used under much higher heads for generation, a case where pumped storage would have an efficiency greater than unity.

Similarly, for double-effect operation, it would also be possible to "over-empty" the basin before the reverse flood-tide generating mode commenced. At the point where the rising ocean water level equals the declining basin water level, the turbines would be started in a pumping mode with flow from basin into the sea. Pumping would again proceed against fairly low heads and, during the subsequent flood generation, the additional space made available in the basin would be used under a considerably higher head (refer Figure A-2).

A plant of this type becomes much more flexible with regard to the timing of its power production, so that it can be more closely adapted to the solar rhythm governing human activity. It would, in principle, be quite capable of producing dependable power at any desired time during the twenty-four hour period. This is illustrated diagrammatically by Figure A-3. However, although the plant can be operated to produce a dependable peak output, a substantial amount of its energy potential would have to be sacrificed in order to be ready for peaking production; in addition, energy would be required from the system to achieve the necessary pumping.

With its flexibility, the single-basin, double-effect development with pumping capability in both directions could, alternatively, be operated to provide maximum revenue. Generally, the value of energy in a power system will vary throughout the 24-hour period. It would be possible to concentrate the energy production into the period of the day when high energy values prevail. An operating period of 14 days, for example, could be optimized so that the returns during this period, including the allowance for the cost of pumping energy, would be a maximum. However, such an operation could not provide for dependable peak production since peak production would have to be sacrificed, at times, for a greater energy production during another period of the day.

Although the addition of a pumping capability to turbogenerators would appear to be an attractive mode of operation, there are critical factors which must be examined before a decision can be made to

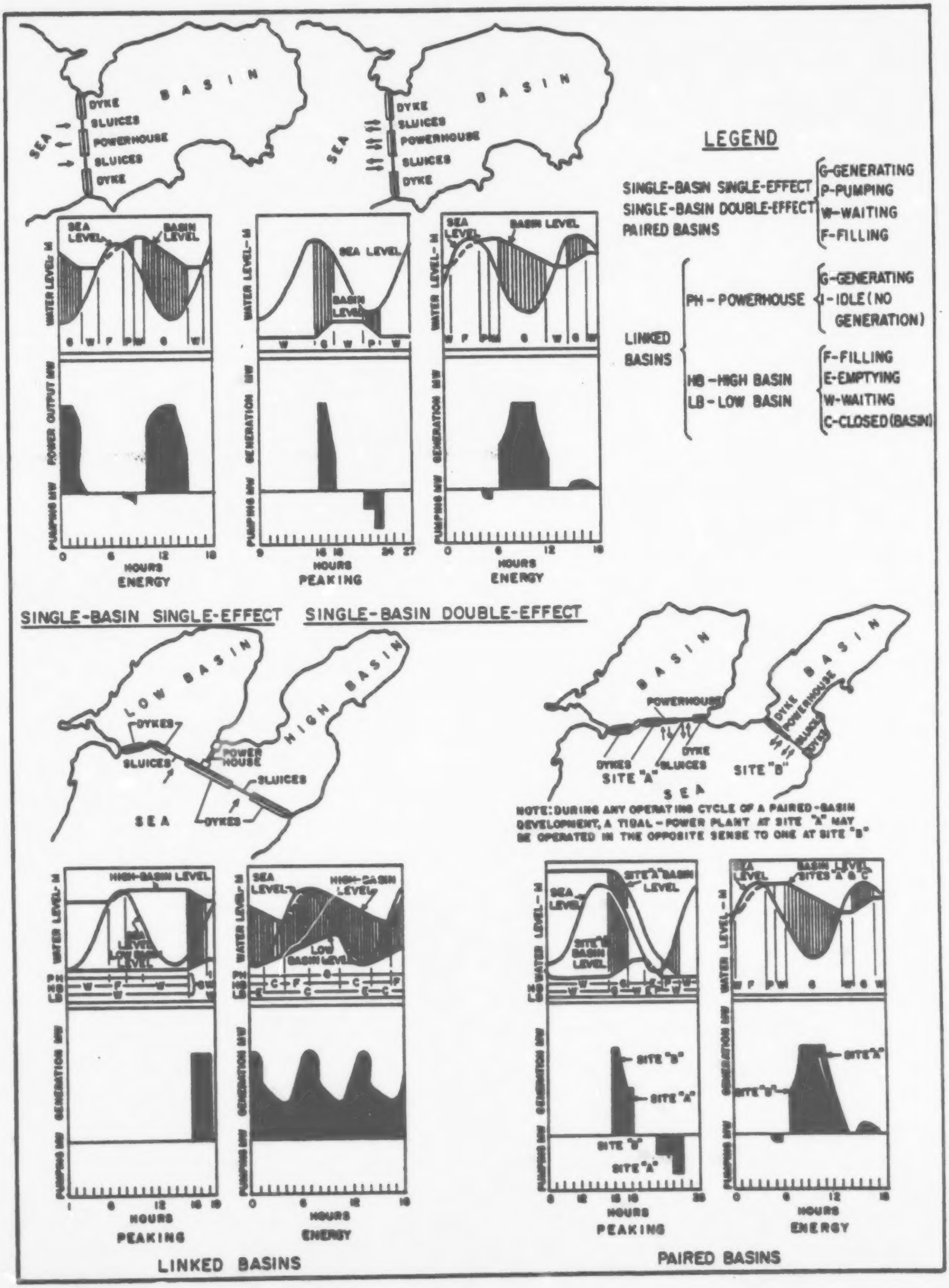

BASIN
DYKE
SLUICES
POWERHOUSE
SLUICES
DYKE
SEA
LEGEND
SINGLE-BASIN SINGLE-EFFECT
SINGLE-BASIN DOUBLE-EFFECT
PAIRED BASINS
G-GENERATING
P-PUMPING
W-WAITING
F-FILLING
LINKED BASINS
PH - POWERHOUSE
G-GENERATING
I-IDLE (NO GENERATION)
HB - HIGH BASIN
LB - LOW BASIN
F-FILLING
E-EMPTYING
W-WAITING
C-CLOSED (BASIN)
SEA LEVEL
BASIN LEVEL
WATER LEVEL-M
POWER OUTPUT MW
GENERATION MW
PUMPING MW
HOURS
ENERGY
PEAKING
SINGLE-BASIN SINGLE-EFFECT
SINGLE-BASIN DOUBLE-EFFECT
LOW BASIN
HIGH BASIN
DYKES
SLUICES
POWER HOUSE
SEA
HIGH-BASIN LEVEL
LOW BASIN LEVEL
LINKED BASINS
POWERHOUSE
DYKES
DYKE
SITE "A"
SITE "B"
NOTE: DURING ANY OPERATING CYCLE OF A PAIRED-BASIN DEVELOPMENT, A TIDAL-POWER PLANT AT SITE "A" MAY BE OPERATED IN THE OPPOSITE SENSE TO ONE AT SITE "B"
SITE "A" BASIN LEVEL
SITE "B" BASIN LEVEL
BASIN LEVEL SITES "A" & "C"
PAIRED BASINS

Figure A-3. Types and Characteristics of Development.

include this capability in the design of the turbines. It has been shown (TPRB, 1977) that the beneficial effect of pumping is derived primarily under lower tidal ranges since the limited turbo-generator output for heads over the rated head deprives pumping of any significant attraction beyond a given tidal range (Cotillon, 1979). Moreover, turbines achieve their greatest efficiency when designed for a single mode of operation at a particular head of water. The wide range of operating heads for a tidal scheme would require some sacrifice of efficiency at the design point so as to achieve reasonably high efficiencies over the range of operating head. If the turbine is designed to work in two directions or to be able to pump, further concessions are necessary to achieve the best overall compromise in machine performance and the cost of turbine control gear would be increased.

To summarize, although pumping at high tide levels into the basin is an apparent attractive mode of operation, it would have the following drawbacks, (Severn Barrage Committee, 1981): (i) there would, at best, be only a small energy gain compared with the output of machines designed for one-way generation only; (ii) the timing of tides would rarely make this mode of operation convenient for the rest of the system; and (iii) the cost of the barrage would be increased and hence the benefit/cost ratio worsened.

In addition, although pumping at La Rance has been found to be attractive overall since the mean tide is approximately 8.5 m and the variation from neap to spring tidal ranges is quite large, the TPRB (1977) pointed out that in Minas Basin the mean tide is 12 metres and the variation from neap to spring is relatively low. The latter's studies confirmed that pumping is most beneficial at low tidal ranges. Morever, at the La Rance tidal electric plant the rated head of the turbines is 5.52 m and the lowest tides are of the order of 3 to 4 metres; accordingly, the use of turbines as pumps at neap tides to increase operating heads during the succeeding generating period increases production not only as a function of the increased head but also by moving the operation of the turbines into the region of higher efficiency. The turbine rated heads in the Bay of Fundy, on the other hand, would be somewhat less than the ranges of the lowest tides which allow the turbines to operate nearer to peak efficiency. Although pumping at the Fundy sites would increase the subsequent production as a function of head, there would be little effect from changes in turbine operating efficiency.

Double-basin Developments

The basic characteristic of the single-basin scheme is that its output of electrical energy is discontinuous and tied to lunar timing with its semi-diurnal and lunar cycles, unless substantial energy is sacrificed to adjust the timing of the output. This discontinuity of output posed a major problem early in this century when each local market was served by, and dependent on, a single source of supply. Obviously, continuity of output from that single source was of prime importance. With the extremely large power systems that now exist, continuity of supply can be assured by the diversity of power sources feeding any given area. A new source is now generally assessed for: (i) the amount of power in kilowatts (kW) it can produce at the time of peak demand; (ii) the amount of energy in kilowatt-hours (kWh) it can produce during a year; (iii) the reliability of its availability; and (iv) environmental effects. However, the characteristics of a large power system will change with growth, so that a source with a continuous output may be needed at times to maintain a balance of generating facility characteristics within the system.

The simplest and least expensive, hydraulically-linked, double-basin scheme is that attributed to Decoeur who suggested it for several locations in Europe in the 1890's. It was subsequently proposed for the International (Canada-United States) Passamaquoddy Project (Interntional Joint Commission, 1961), the development of several estuaries in the upper reaches of the Bay of Fundy (Mines and Resources, 1945) and at other locations (see Appendix C). The popularity of this scheme probably lies in the simplicity and inexpensive installation relative to other multiple basin arrangements and to the fact that it ensures continuous power generation.

The two basins are separated by barrages from the ocean and from each other. This development concept would benefit from a coastal configuration favorable to the creation of the two basins, such as in the case of Shepody Bay and Cumberland Basin at the head of the Bay of Fundy. As illustrated by Figures A-1 and A-3, each basin would be connected by a set of sluices to the ocean. One set would serve to fill the "high" basin from the ocean and the other to drain the "low" basin to the ocean. The powerhouse would be situated in the cut-off dyke between the basins or in the isthmus separating them, depending upon the topography. Generation would take place continuously and always in the direction from the "high" to the "low" basin, so that relatively simple generating equipment, viz. one-way hydraulic turbines, would be required.

From the point of view of power production, the smaller of the two basins would be chosen as the high basin. The operation would proceed as follows, referring to Figure A-3. At the instant of high tide the sluices connecting the upper basin to the ocean are closed. This basin is then emptied through the turbines into the lower basin, which is also closed to the ocean. When the rising level of the lower basin equals that of the falling level of the ocean, the sluices connecting the lower basin to the ocean are opened so that the level in that basin falls with the ebb tide. Thus, the turbines now generate under the head between the upper basin and the ocean. At low water or ebb, the lower basin would again be cut off from the ocean and filled from the upper basin. When the falling level in the upper basin coincides with the ocean level rising on the flood tide, the sluices connecting the upper basin to the ocean are then opened and generation proceeds using the flow from the sea into the lower basin via the upper basin. When inflow ceases at the turn of the flood or high water, these gates are then closed and the cycle is repeated.

A double-basin scheme tends to be relatively higher in capital cost than a single-basin development since the former requires an interconnecting waterway in which the power plant is located, as well as dykes equipped with sluiceways for each basin to control their levels. Moreover, its total energy production would be lower than that from a single-basin scheme using either of the basins. It is obvious that its energy output would have a higher unit cost than that of a single-basin scheme using either of the basins, unless there were particular conditions related to topography or power system demand to favor clearly this type of development.

This hydraulically-linked, double-basin scheme can also be operated to produce dependable peak at a pre-determined time of day as well as continuous but variable amounts of energy, even with one-way hydraulic turbines. The output of such operation is shown diagrammatically in Figure A-3. The production of dependable peak power, again entails some sacrifice of energy since both basins have to be held at their starting positions (maximum level for the high, and minimum level for the low basin) to wait for the time of the dependable peak demand.

Bernshtein (1965) describes several modes of operation of double-basin installations, some requiring turbines with pumping capability others with additional turbine installations in each of the barrages separating the basins from the sea. Even schemes with three basins (Streuben, 1921) have been proposed to obtain a constant head regardless of the tidal phase. These schemes have the objective of continuous output with greater utilization of the tidal energy potential at a site than that available by the simple Decoeur arrangement and mode of operation. However, the more extensive civil works and more sophisticated generating equipment required by such complex schemes results in a higher unit cost of energy.

A recent proposal was put forward to the Canadian Government to reduce the civil costs of a linked, double-basin scheme by a new concept for gate arrangement, which would allow the generation of energy from the high basin to either the low basin or the sea; this concept was dubbed the "delta-connected tidal powerhouse" (Baker and Van Walsum, 1983). In common with other schemes of increasing complexity, the objective of this concept is to reduce the higher civil costs associated with a linked, double-basin development while still maintaining its relative, but decreasing, advantage of continuous power output.

The single-basin, with either single-effect or double-effect turbines, offers the least unit cost of energy and can extract close to the maximum developable potential of the site. This conclusion, as suggested by Bernshtein (1965) and supported by studies of various potential sites (TPRB, 1977 and Severn Barrage Committee, 1981), would not exclude the possibility that the simple double-basin scheme may be better suited because of some specific utility system requirements or other considerations, e.g. navigation.

Paired-basin Developments

If the operations of two single-basin developments were integrated and made complementary, the results would be a "paired-basin" development. Since flexibility of operation is the key attraction of this arrangement, the participating single-basin developments should be equipped for double-effect operation.

Paired basins could allow a continuous production of energy during the day by a judicious choice of water levels in the basins. However, such an operation, achieved at a cost of loss of energy return, would likely be undesirable in a large network. If they were operated for maximum energy production, the operation of each would be the same as if operated separately, provided other conditions of the load demand remained the same. The output would, therefore, be the sum of their energy production.

Actually, the main advantage of this arrangement over an equivalent single-basin would be in dependable peak operation. Ebb operation of one plant would produce an energy output pattern (with respect to time) that would be roughly a mirror image of that produced by flood operation of the other plant. Thus, when two single basin double-effect plants are paired, one can be operated as a high basin and the other as a low basin, or both in the same mode as required, to obtain a more uniform combined peak power production. Typical outputs for peaking and energy operations of a paired-basin development are shown schematically by Figure A-3.

If two single basins could be so located that a sizable phase shift exists between the positions of tide at each site, a paired basin arrangement would be particularly effective and would permit greater flexibility for the production of dependable peak and energy.

Retiming of Tidal Energy

It is evident from the foregoing review of basic tidal power development schemes and modes of operation that the single-basin, single-effect scheme offers the lowest unit cost of energy and can develop the greatest proportion of the potential energy at a particular location. However, its output is available for only two periods of about five hours each per day. Internal retiming or regulation through double-effect operation with pumping would not seem to be economically viable and the use of multiple basins introduces further complexities and adds to the cost. Two practical possibilities exist for marketing of raw tidal energy: one, is that large modern electrical power systems provide a basis for absorption of energy from intermittent generating sources, particularly when the output is entirely predictable in magnitude and time, such as that from a tidal power plant; and the other, an "energy storage system".

Several practical, energy-storage system alternatives include: retiming with an interconnected system having sufficient conventional hydroelectric storage capacity; conventional hydroelectic pumped storage; pumped storage using an underground excavated lower reservoir; and, compressed air energy storage (CAES). Energy storage is technically and economically feasible and has proved to be a highly attractive addition to many modern electric power utility systems. Such additions provide optimal low-cost capacity.

Based on a map study, a number of conventional (surface) pumped storage hydro sites, in the vicinities of tidal Sites A8 and B9 were identified by the Atlantic Tidal Power Programming Board (1969) and by the Bay of Fundy Tidal Power Review Board (1977). More extensive investigation would undoubtedly reveal other attractive sites. In the consideration of attractive sites, the value of abandoned mines should not be overlooked as offering interesting opportunities for pumped-storage development. Pumped hydroelectric storage is the only method of energy storage in general use. However, current development of this alternative must face significant opposition with respect to its environmental implications so that CAES systems may offer an attractive alternative.

The commercial viability of CAES has been enhanced by the highly reliable operation of the 250 MW Huntorf plant in West Germany over a period of 10 years, by the construction of a 25-MW plant at Sesta, Italy and by the current construction of a 1050 MW plant in the Donbass region (north of the Black Sea) in the Soviet Union (EPRI, 1986).

APPENDIX B

EXISTING TIDAL ELECTRIC PLANTS

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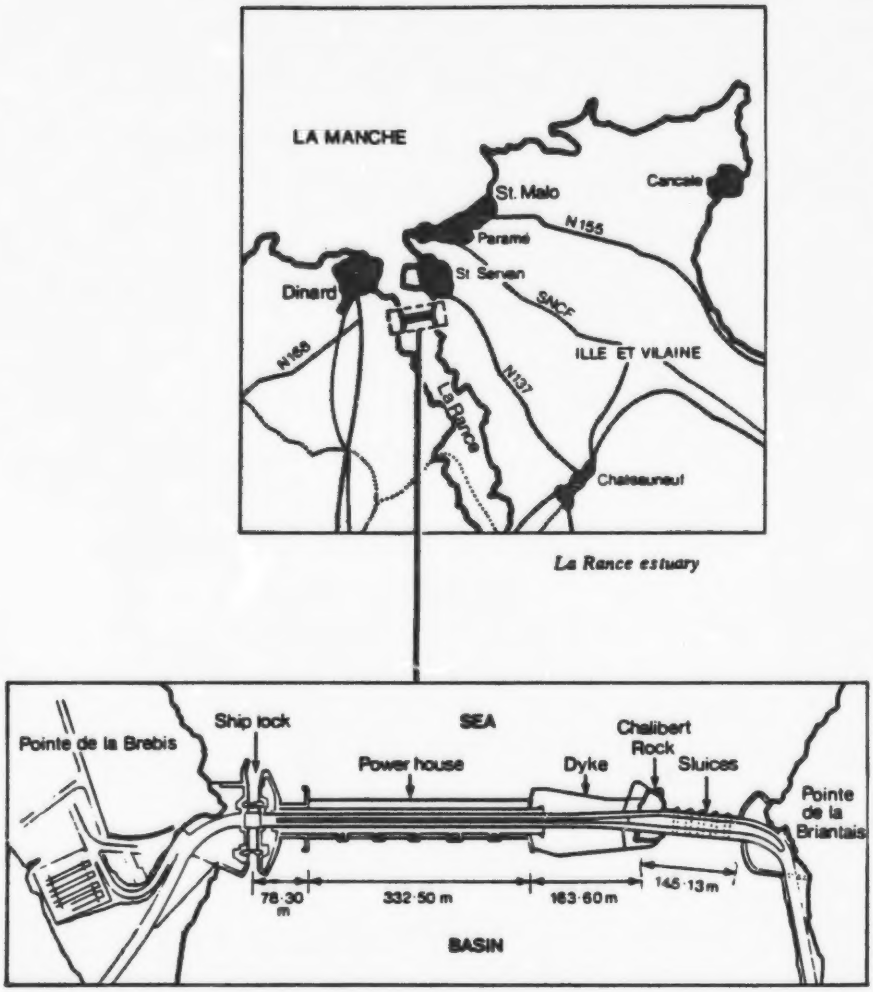
EXISTING TIDAL ELECTRIC PLANTS

Subsequent to World War II, interest in the conversion of tidal energy to electrical energy began to gather momentum. Although a number of tidal electrical plants have been built during the past quarter-century, most are micro-scale projects (<1 MW) except for the Jiangxia plant (3 MW), which may be classified as small-scale, and two larger-scale projects: the 20 MW Annapolis Tidal Generating Station, commissioned in August 1984, and the 240 MW La Rance Tidal Power Station which was commissioned in 1966. Future developments will profit not only from the substantive technological advances during the past 20 years, such as in construction in a marine environment, in turbo-generating machinery and in mathematical simulation techniques, as well as from the information and experience gained in the construction and operation of these modern tidal electric stations, some of which are described briefly hereunder.

La Rance Tidal Power Station

Conceived as a large prototype from which to gain experience for possible development of much larger schemes to harness the tidal energy potential along the Brittany Coast of France, La Rance tidal electric plant was built between 1961 and 1967 with first energy being produced in 1966. The location and plan of the scheme is given in Figure B-1. The following summary description of this unique project has been taken primarily from Cotillion (1979).

La Rance estuary at the project site is about 750 m wide. The barrage consists of a shiplock, powerhouse, a short rockfill section and a 115 m-long sluice structure with six fixed roller gates (15 m wide x 10 m high) capable of passing the flow at mean tides (9600 m^3/s) under a 5 m head. Sectional elevations of the powerhouse, rockfill, dyke and sluiceway are shown in Figure B-2.


LA MANCHE
St. Malo
Cancale
Paramé
N155
St Servan
Dinard
SNCF
N168
ILLE ET VILAINE
N137
La Rance
Chateauneuf
Ship lock
SEA
Pointe de la Brebis
Chalibert Rock
Power house
Dyke
Sluices
Pointe de la Briantais
78·30 m
332·50 m
163·60 m
145·13 m
BASIN

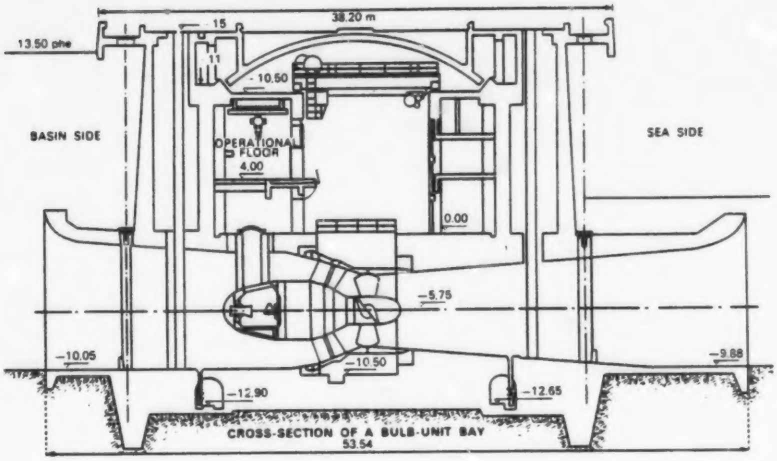
La Rance estuary

Scheme details

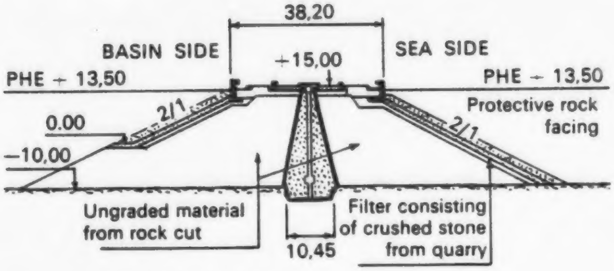
Estuary width:	*750 metres*
Basin area:	*22 square kilometres*
Mean tide:	*8.5 metres*
Installed generating power:	*240 MW*
Turbo-generators:	*24 x 10 MW bulb type Kaplan turbines with reverse flow and pumping capability*
Turbine runner diameter:	*5.35 metres*
rated head:	*5.65 metres*
maximum head:	*11 metres*
minimum head:	*3 metres*

Source: Severn Barrage Committee (1981)

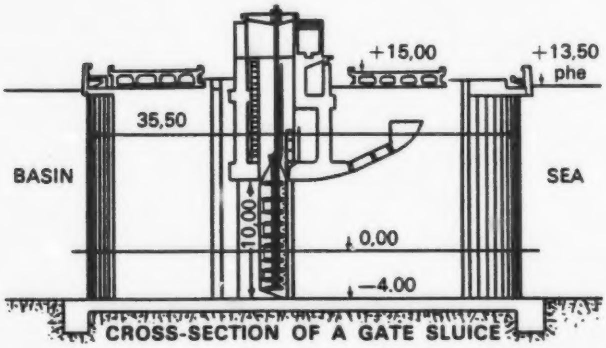
Figure B-1. General Layout of La Rance Tidal Electric Development.


38.20 m
15
13.50 phe
11
- 10.50
BASIN SIDE
SEA SIDE
OPERATIONAL FLOOR
4.00
0.00
−5.75
−10.05
−10.50
−9.88
−12.90
−12.65
53.54

CROSS-SECTION OF A BULB-UNIT BAY


38,20
BASIN SIDE
SEA SIDE
+15,00
PHE + 13,50
PHE + 13,50
2/1
2/1
Protective rock facing
0.00
−10,00
Ungraded material from rock cut
10,45
Filter consisting of crushed stone from quarry

CROSS-SECTION OF ROCK-FILL DIKE


+15,00
+13,50 phe
35,50
BASIN
SEA
10,00
0,00
−4.00

CROSS-SECTION OF A GATE SLUICE

Source: Cotillon (1979)

Figure B-2. Sectional Elevations of Component Structures.

The turbo-generator units are double-regulated, reversible bulb turbines capable of turbining or pumping in both directions. This flexibility was built into the plant, although only a single-basin scheme, in order to provide as much information and experience as possible about the operation of tidal electric plants. Twenty-four machines were installed, with each 5.35 m diameter runner directly coupled to a 10 MW generator-motor with a rated head of 6.65 m. The maximum head is 11 m and the minimum, 3 m.

The sluiceways allow complete emptying of the basin at the end of the direct generation period or complete filling at the end of reverse generation, when the difference in head between basin and sea is smaller that the minimum working head for driving the turbines. i.e. 1.2 m outwards when emptying the basin, or 1.6 m inwards when filling. The sluice section is also used for total filling of the basin in the single-effect, ebb-flow mode of operation. The generating units operate as orifices to assist the sluices.

Tides: The average tide is 8.5 m and is of the semi-diurnal type. Figure B-3 illustrates the variations in tidal range. There is no significant seasonal effect throughout the year but a two-week recurring cycle can be identified, comprising roughly one week with spring tides between 9 m and 12 m, and one week with neap tides between 5 m and 9 m. The ratio between the ranges for ordinary spring and neap tides is of the order of 2.5, and is about 4 between the extremes. Characteristic data for the tides at the La Rance site are provided in Table B-1.

Mode of Operation: The selected rated head at La Rance is 5.65 m and the design flow is 6600 m^3/s, which correspondes to a tide about half way between an ordinary neap tide and the mean tide. Although the rated head results from an economic choice between of the design head of the machines and the design flow of the power station based on the

Table B-1

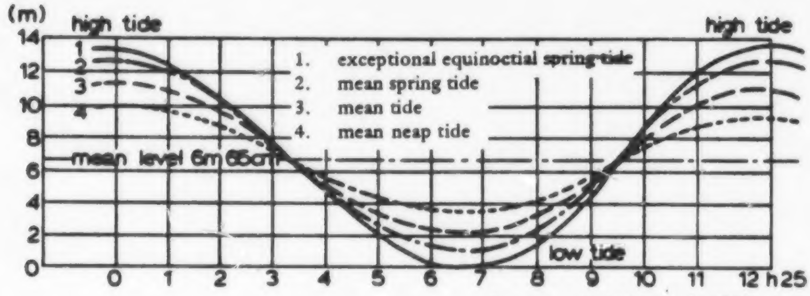
Tidal Characteristics at La Rance Site

	Tidal Coeff.	Tidal Range (m)	Vol. Water Stored ($10^6 m^3$)	Discharge (at flood) (m^3/s)
Equinoctial spring tide	120	13.5	184	18,000
Ordinary spring tide	93	10.9	150	12,900
Mean tide	70	8.5	110	9,400
Ordinary neap tide	45	5.0	65	5,500
Minimum neap tide	35	3.5		4,000
Mean water level		6.7		

characteristics of the tide and basin site, it should be noted that the rated head is lower than the available head for spring tides. The rated head is the minimum head for which the rated output (maximum output) can be reached. Because of the aforementioned two-week cycle, two-way or double-effect operation involving a reduced active head is attractive during 3 or 4 days of that cycle and single-effect operation is satisfactory during the remaining period. When the actual head is less than the rated head, the turbines are operated between maximum output and the output corresponding to maximum efficiency in order to have a large enough discharge so that the flow from the basin will produce the required energy.

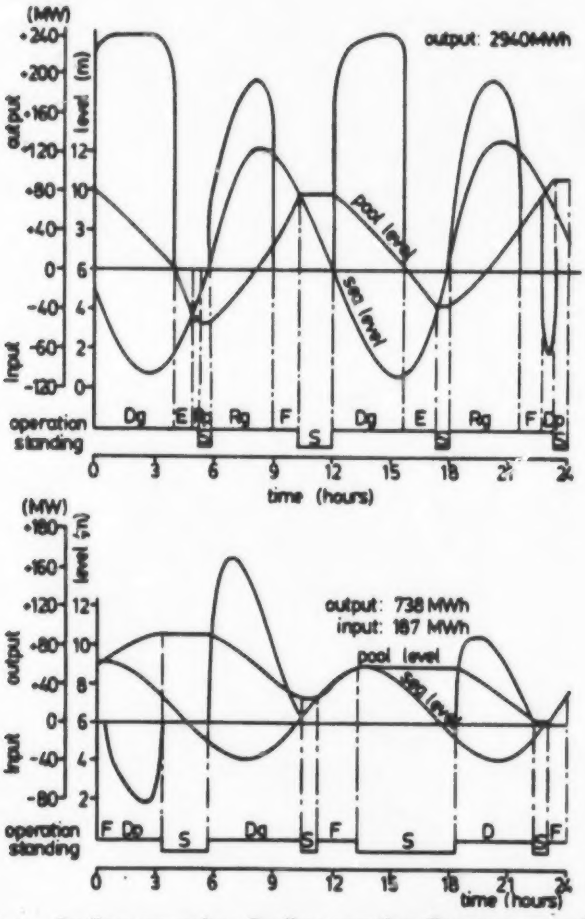
A further factor that had to be taken into account due to the variation in ranges was the difference in output between a day of spring tide and one of neap tide. Figure B-4 illustrates the outputs for ranges in tide of 11 m and 5 m. The ratio between the outputs is about 4; without pumping, it would be in the order of 6 since for the spring tide the head would have been 3 times greater and the generation period twice as long as for the neap tide.

Operational Experience: It was found that for tidal ranges greater than about 11 m, the output is significantly greater under the



Source: Cotillon (1979)

Figure B-3. Variations in Tidal Ranges at La Rance.



Note: Dg-direct generation; Dp-direct pumping; Rg-reverse generation; Rp-reverse pumping; E-emptying; F-filling; S-standing.

Source: Cotillon (1979)

Figure B-4. Operational Mode and Output for Large and Small Tidal Ranges.

double-effect mode. Moreover, the limited output for heads greater than the rated head deprives pumping of any significant attraction beyond a given range and single-effect operation generates less energy than double-effect. Based on operating experience, Cotillion (1979) suggests the following guidelines for the operation of a single-basin tidal project, e.g. La Rance, should be as follows: (i) for spring tides, i.e. tidal ranges greater than 11 m, double-effect generation is of interest because of the limited output of the machines; (ii) for tides ranging between 7 m and 11 m (specific figures apply to La Rance only since the observations are dependent on site and machine characteristics) either reverse generation or appropriate direct pumping may be considered, although in the former case there is a more continuous supply of power but a loss of energy; (iii) for neap tides, i.e. under 7 m, direct pumping has to be considered from the point of view of profit in terms of energy quantity or energy value; and, (iv) reverse pumping should be associated with reverse generation, whenever profitable. To maximize output with ranges over 11 m, the operation should comprise direct and reverse turbining, without pumping, and, under 11 m ranges, direct turbining with appropriate pumping.

The turbines had been immersed for over 130,000 hours and had operated for about 90,000 hours when they were examined in 1982 and were found to have suffered no notable oxidation. The only major fault has been the failure of the lugs holding the generator stators in position in the bulb housing. This condition was caused by the severe stresses during the start up for pumping which is "direct on line"; otherwise, problems have been of a minor nature similar to those one might expect in an electrical operating plant. The overall plant availability, excluding the problem with the fixing lugs, has been about 93%. By carrying out routine maintenance during neap tides, loss of energy is kept to a minimum so that energy availability has been about 96%. The total net electricity output has been about 0.5 TWH/year. The flexibility of the double-effect operation enables the plant to respond occasionally to unscheduled requests for energy. There has been no problem with sedimentation, no vibration of the units and no corrosion problems. The power station has been operating satisfactorily (Hillairet, 1984).

A comprehensive impressed-current cathodic protection system was incorporated into the scheme. This system uses about 20 kW and has been successful in preventing corrosion of the stainless steel runner blades and removable draft tube adjacent to the runner as well as the normal steel used for the bulb, the draft tube liner and other submerged metal parts. Although a sophisticated paint system had also been used on the normal steel components this would not now be considered necessary in view of the success of the cathodic protection. In addition, to test the reaction of different materials to sea water corrosion, 12 of the turbines were fitted with stainless steel runner blades and 12 with aluminum bronze blades. An inspection of some of the runners by the writer in 1979-80 showed them to be in excellent condition, with even large areas of the blades still covered with original paint.

When generation starts, a turbine can be brought up to synchronous speed in less than a minute. Thus, all turbines could be brought on line in less than two minutes, although, care has to be exercised over the rate at which the turbines and gates are opened and closed in order to avoid waves travelling up and down the estuary.

The 24-turbo-generator installation does not represent the optimum installation for this estuary, which should be in the range of 40 units, but rather, it reflects the amount of money that was allocated to the project. Cotillon (1979) states that La Rance is not only a source of valuable lessons but also an economically attractive power station since the standard cost of tidal energy generated in 1976 was equal to the average cost of a nuclear kWh and also equal to the average thermal kWh cost.

Tidal Electric Stations in China

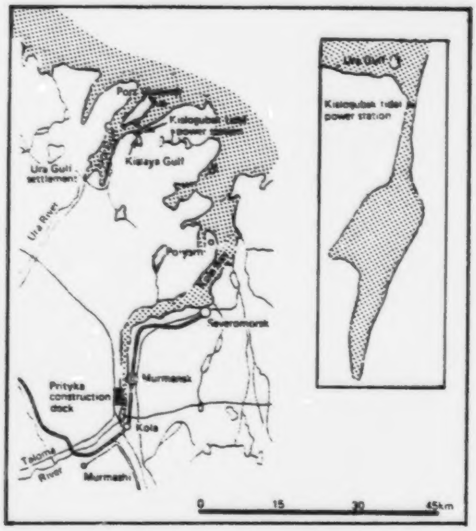
It has been difficult to obtain detailed information on tidal electric stations in China. According to Modern Power Systems (1981), China began to study the exploitation of tidal electric power in the mid-1950's and a 40 kW single-effect tidal electric plant was completed in 1959 in Zhejiang Province and it has now been enlarged to give it a 200 kW capacity. Another single-effect plant, with a capacity of 155 kW, was built on Jingang Creek in Shandong Province in 1970. It has 3-55 kW turbo-generators all made by a local machinery plant. This small station, jointly run by nine villages in a rural peoples' commune, supplies cheap power for farms and lighting for peasant's homes. About 280 pumping stations driven by tidal energy have been built along the coast of Guangdong Province since 1958.

In the 1970's there were 6 tidal plants with 19 turbines, aggregating more than 1900 kW, installed successively in Zheijiang, Jiangsu and Shandong provinces. The maximum ranges at the sites vary from 3.5 m to 7.8 m and the installed unit capacities range between 75 kW and 160 kW (Zhu, 1980).

In April 1980, the Jiang Xia tidal electric plant, with an ultimate installed capacity of 3000 kW from 6 bulb units, 2.5 m diameter and delivering 500 kW each, was commissioned in Wenling County, Zhejiang Province. The maximum range of the tide at this site is 8.39 m. This plant together with the micro-tidal, Lui He Kuo plant in Jiangsu Province operate in the double-effect mode (Cheng, 1985). The Jiang Xia station feeds a small grid supplying villages 20 km distance through a 35-kVA transmission system.

Kislaya Guba Experimental Project

The small Kislaya Guba experimental tidal electric plant was put into operation in late 1968 with one unit of 400 kW capacity (the plant



Ura Gulf
Kislogubsk tidal power station
Kislogubsk tidal power station
Kislaya Gulf
Ura Gulf settlement
Ura River
Severomorsk
Murmansk
Prityka construction dock
Kola
Tuloma River
Murmashi
0
15
30
45km

Figure B-5. Location of Kislaya Guba Tidal Electric Station.

is designed for two such units), about two years after the commissioning of La Rance station, at the mouth of Kislaya Gulf, 100 km north of Murmansk on the shores of the Barents Sea (Bernshtein, 1972). The location is shown in Figure B-5. The USSR has considerable tidal energy potential, amounting to an estimated 1/10th of the developable tidal energy resources in the world. However, these sites are located on the coasts of the Barents Sea, the White Sea and the Sea of Okhotsk, in uninhabited regions with a rigorous climate.

It was decided in 1962 to construct the Kislaya Guba station as an experimental plant to verify the application, under the particular physical and climatic conditions of the region, of the float-in-place method of construction, i.e. caissons, at that time a relatively immature technology. The application of this method under USSR conditons, i.e. where the best sites for building tidal electrical stations are located on rocky coastlines with difficult land approaches and a bleak climate, seemed to offer considerable advantages, particularly since the station or floating components could be built in the favourable conditions of a sea coast industrial centre, towed in a completed state (with equipment already assembled) to the site and sunk onto prepared foundations. Since the solution to problems that arose during construction of this experimental plant could be of value for hydraulic construction in general, and under the rigours of the far northern regions in particular, a broad program of comprehensive investigations was an integral part of the project.

The particular location of this scheme was selected primarily to require minimum work to close off the bay which would become the tidal basin for the station. The neck connecting the gulf to the Barents Sea is only about 50 m wide. Although the tide at Kislaya Guba has a range between 1.3 m and 3.9 m which would not make it an economic development, the site is relatively close to Murmansk which could benefit from its output. However, with the relatively low range, it was possible to carry out investigations of the power characteristics of the installation under the most complicated conditions.

In the natural state, the tide filled the 1.14 km^2 bay through the narrow neck within 6 h 12 min. obviously producing high speeds up to 3 m/sec. with the flow attaining values of 300 m^3/sec. The depths at the site were about 4 m to 5 m and the bottom was of unconsolidated marine sediments of 5 m to 7 m thick. In the preparation of the site to receive the caisson, the deposits were excavated to a depth of 5 m by a floating crane (lifting capacity of 10 tons) equipped with a set of grab buckets. The total volume of excavated material was 25000 m^3. However, the site preparation ran into a number of difficulties and its costs proved to be high. Recent techniques developed in connection with the Deltaworks Plan would be significantly more cost-effective.

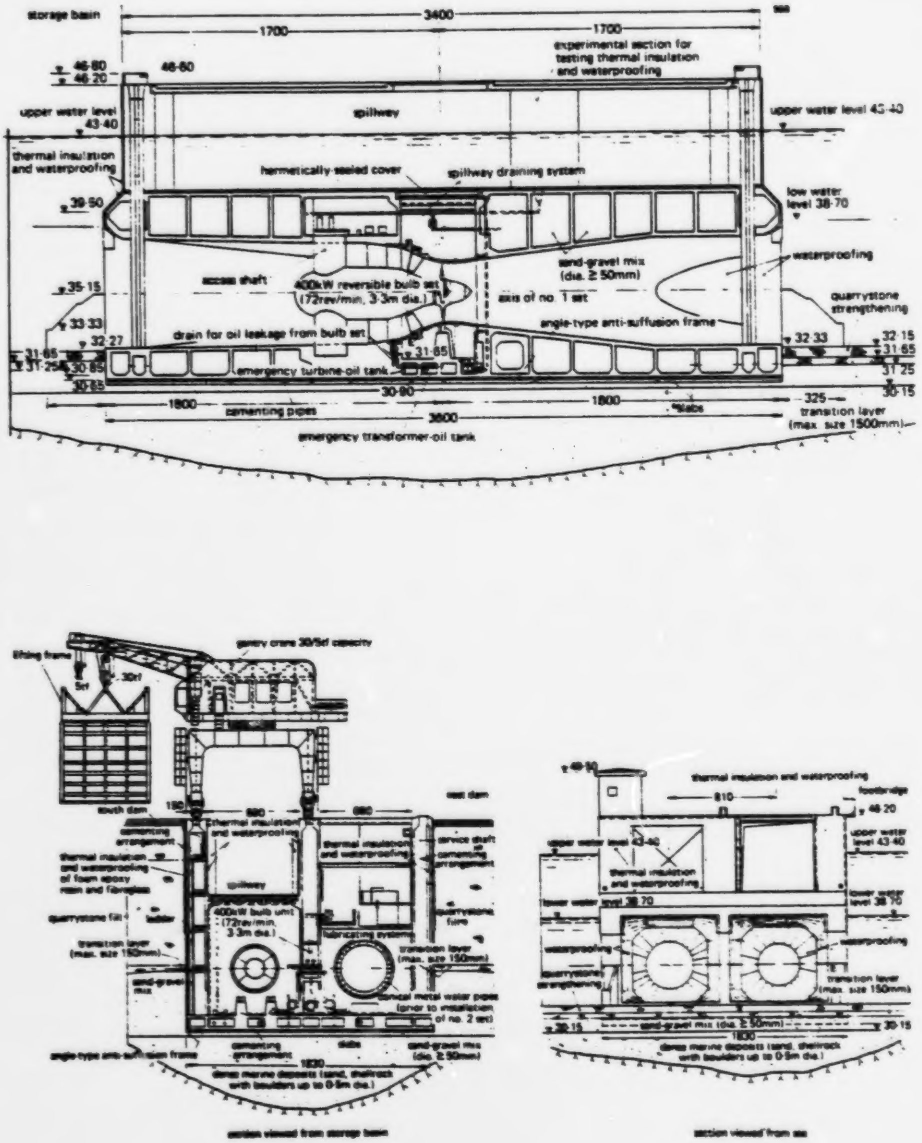
A sectional elevation and typical cross-sections of the powerhouse are shown in Figure B-6. It is not known whether the second 400 kW unit has yet been installed since it has been difficult to obtain additional information on this project. An attempted visit by the writer, when he was in Moscow in 1975, to the remote site of this experimental station was refused by Russian authories as not feasible.

Bernshtein (1974) has indicated that the experimental station has yielded much valuable information regarding construction and placement techniques, including foundation preparation and concrete durability under the harsh climatic conditions.

The Annapolis Tidal Generating Station

This project was carried out by the Tidal Power Corporation and commissioned in August 1984. The Government of Canada provided a capital contribution of $25 million toward total project costs estimated at $46 million. Nova Scotia Power Corporation undertook to design, construct and operate the plant, and to purchase the output at displacement energy values. Tidal Power Corporation undertook to provide the balance of capital, accept the risks of ownership and guarantee a minimum four-year demonstration. The purpose of the installation is to evaluate the operational characteristics of a large diameter (7.6 m) Straflo turbine and the potential use of such turbines for tidal power developments in the Bay of Fundy and low-head river developments in Canada.

In its role as a demonstration unit, instrumentation was installed to monitor the performance of the turbo-generator, particularly


storage basin
3400
1700
1700
sea
experimental section for testing thermal insulation and waterproofing
46·80
46·20
46·60
upper water level 43·40
spillway
upper water level 43·40
thermal insulation and waterproofing
hermetically-sealed cover
spillway draining system
39·50
low water level 38·70
sand-gravel mix (dia. ≥ 50mm)
waterproofing
access shaft
400kW reversible bulb set (72rev/min, 3·3m dia.)
axis of no. 1 set
35·15
quarrystone strengthening
33·33
angle-type anti-suffusion frame
drain for oil leakage from bulb set
32·27
31·65
32·33
32·15
31·65
31·25
30·85
30·65
emergency turbine-oil tank
31·25
30·15
30·90
1800
1800
325
cementing pipes
slabs
transition layer (max. size 1500mm)
3600
emergency transformer-oil tank
gantry crane 30/5tf capacity
lifting frame
5tf
30tf
east dam
south dam
180
cementing arrangement
thermal insulation and waterproofing
thermal insulation and waterproofing
service shaft
cementing arrangement
thermal insulation and waterproofing of foam epoxy resin and fibreglass
spillway
quarrystone fill
ladder
400kW bulb unit (72rev/min, 3·3m dia.)
quarrystone fill
lubricating system
transition layer (max. size 150mm)
transition layer (max. size 150mm)
sand-gravel mix
conical metal water pipe (prior to installation of no. 2 set)
angle-type anti-suffusion frame
cementing arrangement
slabs
sand-gravel mix (dia. ≥ 50mm)
1830
dense marine deposits (sand, shellrock with boulders up to 0·5m dia.)
48·50
thermal insulation and waterproofing
810
footbridge
46·20
upper water level 43·40
upper water level 43·40
thermal insulation and waterproofing
lower water level 38·70
lower water level 38·70
waterproofing
waterproofing
quarrystone strengthening
transition layer (max. size 150mm)
30·15
sand-gravel mix (dia. ≥ 50mm)
30·15
1830
dense marine deposits (sand, shellrock with boulders up to 0·5m dia.)

section viewed from storage basin

section viewed from sea

Source: Bernshtein (1972)

Figure B-6. Sectional Elevations of Kislaya Guba Powerhouse Caisson.

that of the hydrostatic seals which are key components of the Straflo turbine. A program has been developed to monitor certain environmental impacts, such as drainage and salt water instrusion into the valuable agricultural lands surrounding the basin. This latter programme should enable the tidal electric station to be operated for maximum energy output with minimal adverse environmental impacts.

Information concerning the Annapolis Station has been extracted from Douma (1984) and DeLory (1986).

The project is located in the lower reaches of the Annapolis River at Annapolis Royal, Noval Scotia (Figure B-7). It makes use of the existing barrge, consisting of a causeway and sluice gate structure constructed across the river in the early 1960's to provide protection to the dyked marshland against flooding by the tides so as to allow more intensive agricultural use of those marshlands and also to accommodate a highway across the river. Before construction of the barrage, the average range in water level in the river reservoir area was about 6.4 m but, after closure, the difference has amounted to only about 0.4 m. The presence of the structure has thus, provided stable water levels immediately upstream. Although these water levels are higher since the project commenced operation, they will not exceed the present maximum water levels during the periods when the river is in flood (Rice, 1984).

The existing water control structure is of reinforced concrete and contains two gated-sluice openings each 9.2 m wide by 7.3 m high and one fish-pass opening, 3 m wide by 7.3 m high at an elevation 1.83 m higher than the sluice opening. The water levels on the river side are maintained by the electrically-operated, verical sluice gates. These gates and their seals are designed to prevent intrusion of sea water into the basin and thus prevent flooding at high tide. The gates are raised to permit the discharge of river flow, as required, to maintain the water level in the reservoir. Consequently, the existing control gates are

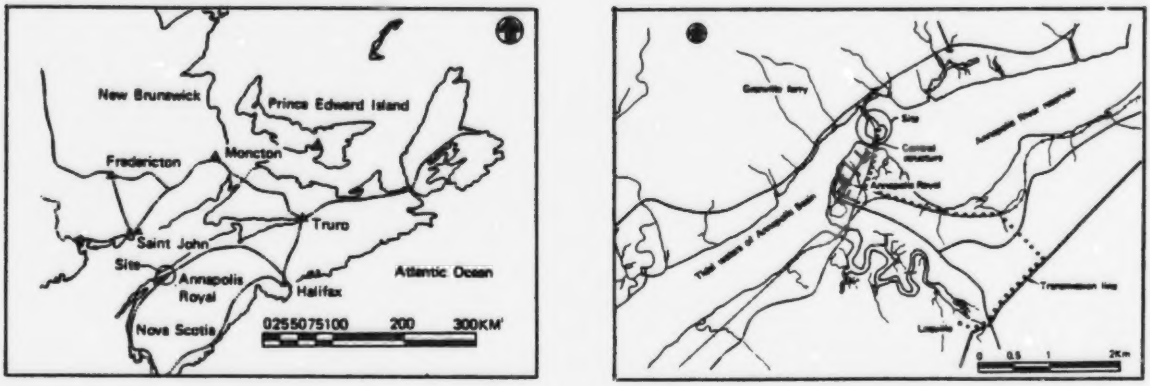

New Brunswick
Prince Edward Island
Fredericton
Moncton
Truro
Saint John
Site
Annapolis Royal
Halifax
Atlantic Ocean
Nova Scotia
0255075100 200 300KM
Granville ferry
Site
Control structure
Annapolis Royal
Annapolis River reservoir
Tidal waters of Annapolis Basin
Transmission line
Lequille
0 0.5 1 2Km

Figure B-7. Location of Annapolis Tidal Power demonstration Project.

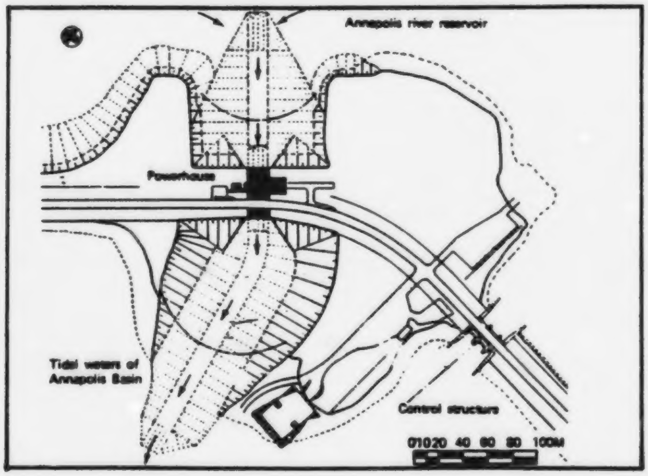

Annapolis river reservoir
Powerhouse
Tidal waters of Annapolis Basin
Control structure
01020 40 60 80 100M

Figure B-8. Site Layout of Annapolis Tidal Power Demonstration Project.

equipped with seals only on the reservoir side, since they are closed at high tide to prevent sea water entering the river. As an integral part of the tidal power development, the gates will have to be in the closed position during low tide and, therefore, the gate seals were modified to accommodate the new regime. The fish pass is not equipped with a gate so as to permit the free movement of fish between sea and river, depending on tide levels. The maximum discharge at low tide amounts to approximately 500 m^3/sec for the sluice openings and a maximum of 80 m^3/s for the fish passage. The site layout for the demonstration project is shown in Figure B-8.

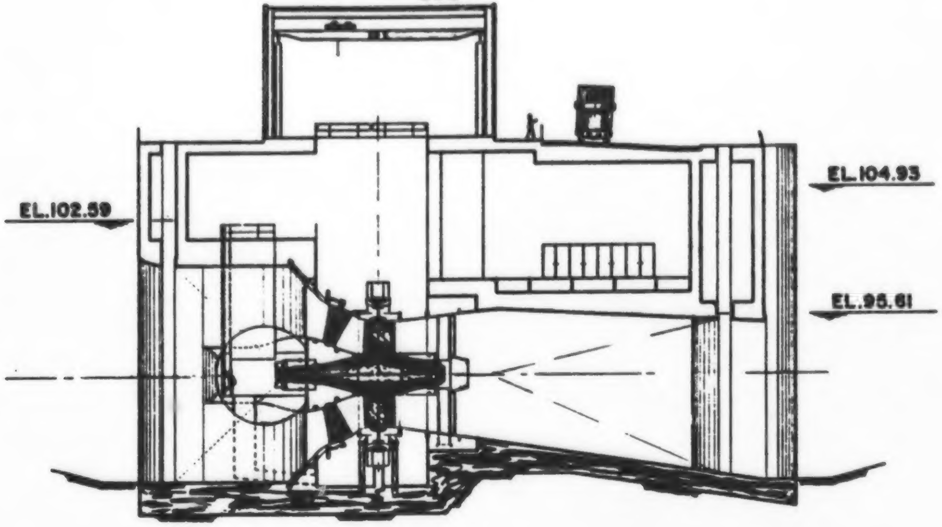
The turbine is a single-effect Straflo unit designed to generate power during flow from reservoir into the sea. When sea level is higher than reservoir level, the water passages of the turbine are used to sluice sea water into the river reservoir or tidal basin during each tidal cycle. A longitudinal section of the powerhouse, together with several cross-sectional views, is shown on Figure B-9. The mean parameters of the Annapolis Straflo turbine are given in Table B.2.

Table B-2

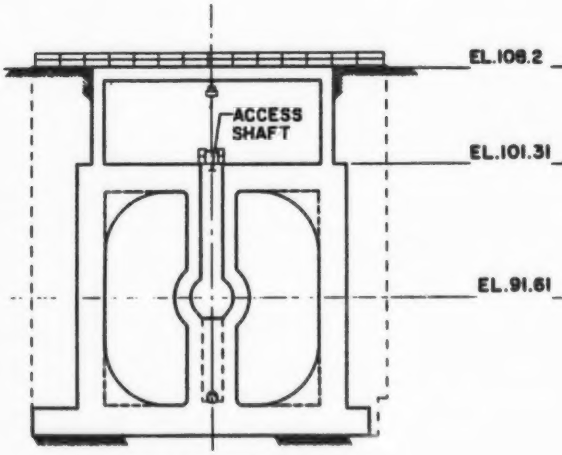
Main Parameters of Annapolis Straflo Turbine

Diameter of runner	7.6 m
Number of blades	4
Number of distributor gates	18
Normal operating head range	1.4 to 6.8 m
Maximum operating head	7.1 m
Rated operating head	5.5 m
Output at rated head	17.8 MW
Maximum output	19.9 MW
Discharge at rated head	378 m^3/sec
Efficiency for full load at rated head	89.1%
Rated speed	50 r.p.m.
Runaway speed	98 r.p.m.
Annual generation	50 GWh

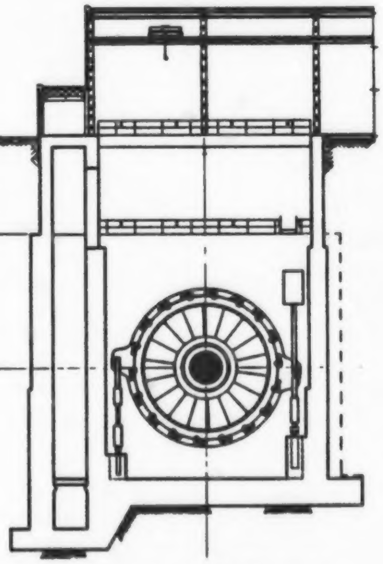
The power station is linked to the Nova Scotia transmission grid by means of a 69 kV line approximately 5 km in length.


EL.102.59
EL.104.93
EL.95.61

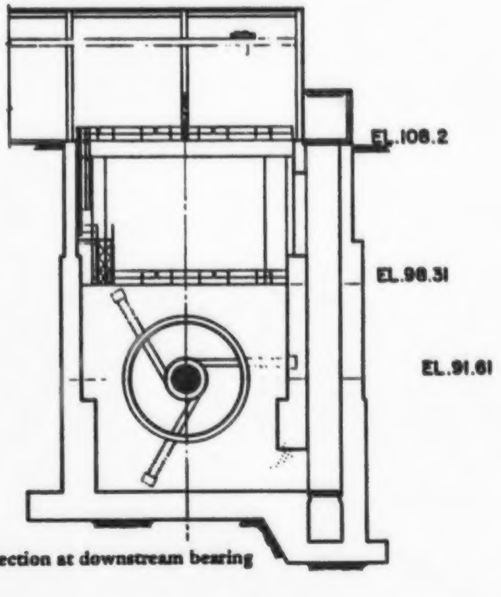
Longitudinal section of powerhouse


EL.108.2
ACCESS SHAFT
EL.101.31
EL.91.61

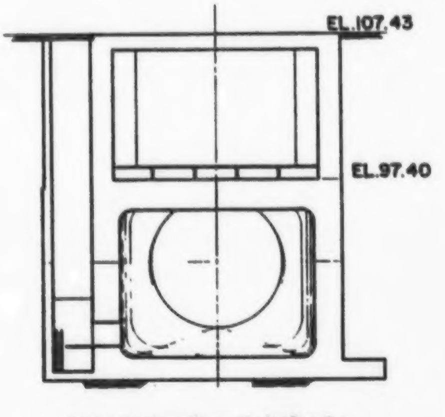
Cross-section through intake pier



Cross-section at distributor gates


EL.108.2
EL.98.31
EL.91.61

Cross-section at downstream bearing


EL.107.43
EL.97.40

Cross-section through draft tube

Figure B-9. Sectional Elevations of Annapolis Tidal Electric Station.

As reported by DeLory (1986):

> "During its first year of operation, the plant had an availability rate of 99% missing only 8 tides out of a possible 728. Seventy-five percent of the generation runs have gone the full tidal period without incident. Twenty-five percent of the runs have experienced interruptions for short periods of time due to mechanical difficulties in the auxiliary systems.
>
> In June 1985 the first major inspection of the machine occurred. All hydrostatic seals were found to be in good shape. The upstream standstill seal was damaged. It is not known exactly what happened to it, but it is felt that it was damaged during startup. Possibly during the strike period [a labour dispute resulting in sporadic work stoppages from May 1983 until the end of that year] the seal became glued to the rim. This is backed up by the extraordinary force required to turn the rotating parts during the initial rotation for balancing, etc. The runner blades showed no sign of cavitation or corrosion, however, a small amount of pitting was found on the runner hub. All other metal parts, distributor/wicket gate assembly, upstream and downstream casings, etc. were in original condition indicating the cathodic protection was doing its duty very well.
>
> Considering this unit is a pilot plant and set to bring out any difficulties which could then be attended to in a much larger installation, its operation is most pleasing to the owner and the supplier."

APPENDIX C

SOME EARLY SURVEYS AND STUDIES

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SOME EARLY SURVEYS AND STUDIES

Beginning in the 1940's and up until the mid-1960's, there were a number of studies and surveys undertaken to examine the possibilities of harnessing some of the energy of the Fundy tides. The studies were generally of a superficial nature and the sites were selected more or less arbitrarily. The results of these are described very briefly to indicate an increasing interest in this renewable resource leading up to the first comprehensive feasibility investigation of tidal power in the Canadian Bay of Fundy. Locations are shown in Figure C-1.

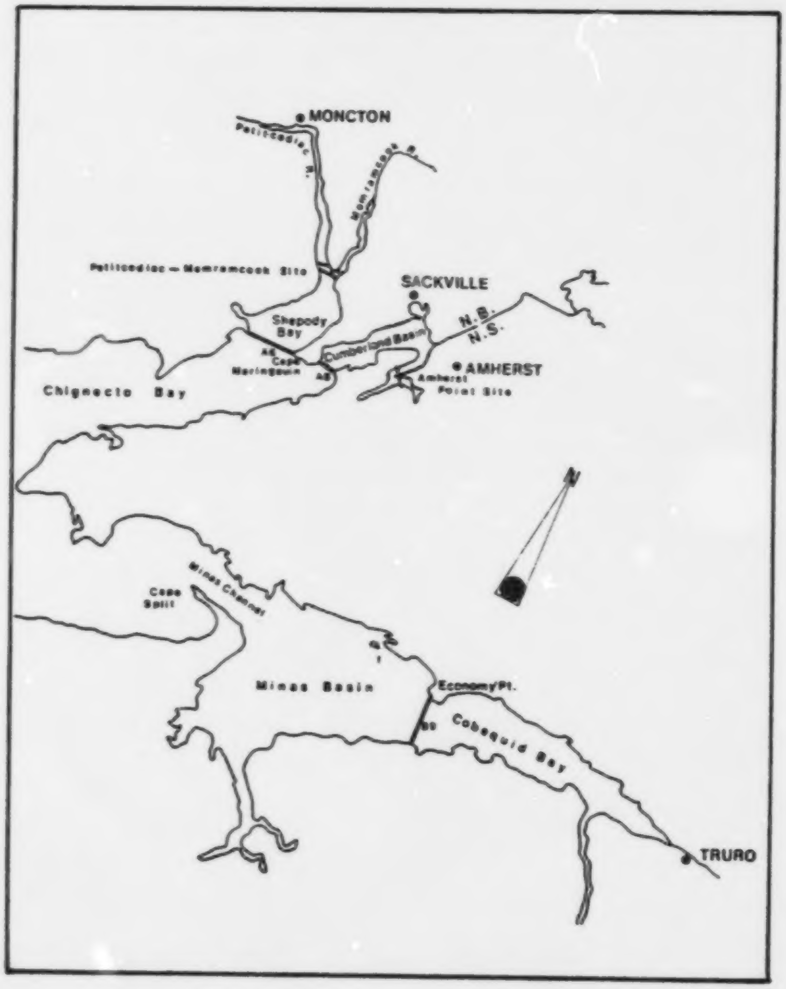
MONCTON
Petitcodiac R.
Memramcook R.
Petitcodiac — Memramcook Site
SACKVILLE
Shepody Bay
A6
Cape Maringouin
A8
Cumberland Basin
N.B.
N.S.
AMHERST
Amherst Point Site
Chignecto Bay
N
Cape Split
Minas Channel
Minas Basin
Economy Pt.
B9
Cobequid Bay
TRURO

Figure C-1. Location of Early Surveys.

Minas Basin

The flow through the Minas Channel past Cape Split at times exceeds 850,000 cubic metres per second (more than 100 times the ordinary flow of the St. Lawrence) and velocities attain four to five metres per second. Water depths of up to 140 metres have been found in the Minas Passage.

In 1956, the Montreal Engineering Co. prepared a brief report for the Nova Scotia Light and Power Co. on a Cape Split project. They concluded that while they were confident that Minas Basin power would ultimately be developed, it would be uneconomic and wasteful to develop it at that time. Their report considered a single-basin project and also a double-basin project with a connecting power plant.

In 1957, a report by Foundation of Canada Engineering Corporation Ltd., (FENCO), included consideration of the Minas site with a peaking installation of 2 million kilowatts and up.

They commented as follows:

> "Minas Basin, because of its enormous area and potential possibilities, by far looks as the best tidal power site in the Bay of Fundy, but unfortunately, without extensive dyke construction, cannot readily adapt itself for the two-basin scheme. It appears to be, however, a very good site for a single basin scheme which, when developed, could be tied with some other tidal plant to firm up its production."

The FENCO report concluded that the Shepody-Cumberland project was best suited for early development.

Between July 1965 and March 1966, Huntec Ltd. of Toronto carried out a geological-geophysical study of the Minas Passage and areas reaching up into the Minas Basin. This work was done for the Atlantic Development Board and has resulted in reports and maps recording sea-bottom, bedrock soils and geologic conditions of both the land and offshore areas. Briefly, the study indicated an irregular sea bottom with water depths of up to 140 metres and an even more irregular bedrock surface. The Huntec report further notes that:

> "Distribution of unconsolidated sediments is more widespread than anticipated, though much of the Minas Passage itself is swept clean by tidal currents. Overburden thicknesses up to 330 feet are observed in the eastern end of the Minas Passage. It will be difficult, though not impossible, to locate a tidal dam in the Minas Passage area without traversing a substantial thickness of unconsolidated sediments."

Shepody Bay - Cumberland Basin

These two projects, capable of individual or joint construction, were assessed in a preliminary manner by the 1959 report of FENCO. After a review of a number of tidal sites that report concluded in part:

> "The investigations carried out for this preliminary report indicate that the most suitable location for the first tidal plant is at the mouths of Shepody Bay and Cumberland Basin. This site, apart from exceptionally high tides, has excellent expansion possibilities and, therefore, allows for development of the power plant in stages."

The FENCO report contemplated three stages of development with 450,000, 900,000 and 1,800,000 kilowatts of installed capacity, respectively. Firm energy at the second stage would cost 7.9 mills per kwh and guaranteed secondary energy 5.9 mills per kwh. The Corporation noted the possibility of more economic operation if the plant could be used as a peaking project.

The FENCO proposal contemplated a 6,600 metre long dam and powerhouse structure across Shepody Bay and a similar 4,000 metre project across Cumberland Basin. The basins controlled by the projects would cover 155 and 105 square kilometres respectively, and the average tide would be 10.5m.

FENCO prepared a further report on the project in 1962 and in the following year undertook for the Atlantic Development Board a survey of subsurface conditions in the project area. The report of that survey was submitted to the Board in June of 1964 and concluded in part as follows:

1. "The geophysical results indicate that rock is available as a foundation for all structures at the Shepody Bay site at depths generally not exceeding 120 feet below geodetic datum. At the Cumberland Basin site ... bedrock is sloping from about El. 0' to El. - 120' except for a narrow zone of 800' in which it falls to El. - 180'."
2. "The rock is a sound, interbedded sedimentary formation of shales and sandstones..."
3. "It may be inferred from the geological and geophysical information available that compact silty sand till is generally available at depths not exceeding 100'."
4. "... the confirmation of soundness of the foundation will make it possible to install more units than assumed in the 1962 report, for the purpose of computing energy costs. This would indicate that the unit cost of energy can be reduced by spreading the relatively fixed cost of much of the civil works over a larger energy output."

Amherst Point

A two-pool arrangement in this area was studied by the Nova Scotia Power Commission in 1956. It was considered as a possible experimental pilot plant providing data for future larger tidal power stations. Incoming tides would be routed through a gated cut across Amherst Point into the Maccan River estuary which would provide a "high pool" with an area of 6.5 square kilometres. A dam and powerhouse structure would be constructed across the estuary near the southern tip of Amherst Point. The "low pool" of 3.9 square kilometres would be formed in the Hébert River estuary and controlled by a gated structure extending from Amherst Point across the upper reaches of the Cumberland

Basin to Minudie. The range of tides at this location varies between 8 m and 15.8 m. The power production of the scheme was estimated as being 12,500 kilowatts for 100% of the time; 14,500 kilowatts for 93% of the time; and 16,500 kilowattas for 85% of the time.

Petitcodiac-Memramcook

The governments of Canada and New Brunswick undertook a joint study of tidal power possibilities at this location in 1944. The study was carried out by H.G. Acres & Co. who submitted their report in October of 1945. The site itself appeared ideally suited for tidal power development, having a tidal range of 6.4 m to 15.8 m and including two tidal estuaries lying side by side within a very short distance. A two-basin development was studied which would produce continuous (firm) power. A copy of the proposed layout is shown on Figure C-2.

The Company concluded, in part, as follows:

> "It is feasible to construct the required works, although some portions of them will involve unusual difficulties."
>
> "The potential average annual energy production of tidal power is approximately 1,310,000,000 kilowatt-hours. If all of this could be sold, the production cost would be 12.2 mills per unit. However, on the basis of supplying 73,000 electrical-horsepower of firm commercial power with an annual load-factor of 61.0 per cent, as described in Section No. 13, the annual production amounts to 291,000,000 kilowatt-hours at a cost of 54.7 mills per unit."
>
> "... the installation of only part of the ultimate generating capacity would result in much higher figures for the capital cost per horse-power and for the annual costs for each kilowatt delivered by the station. In other words, if the economics of the complete development are unfavourable, those of the partial installation would be even more so."

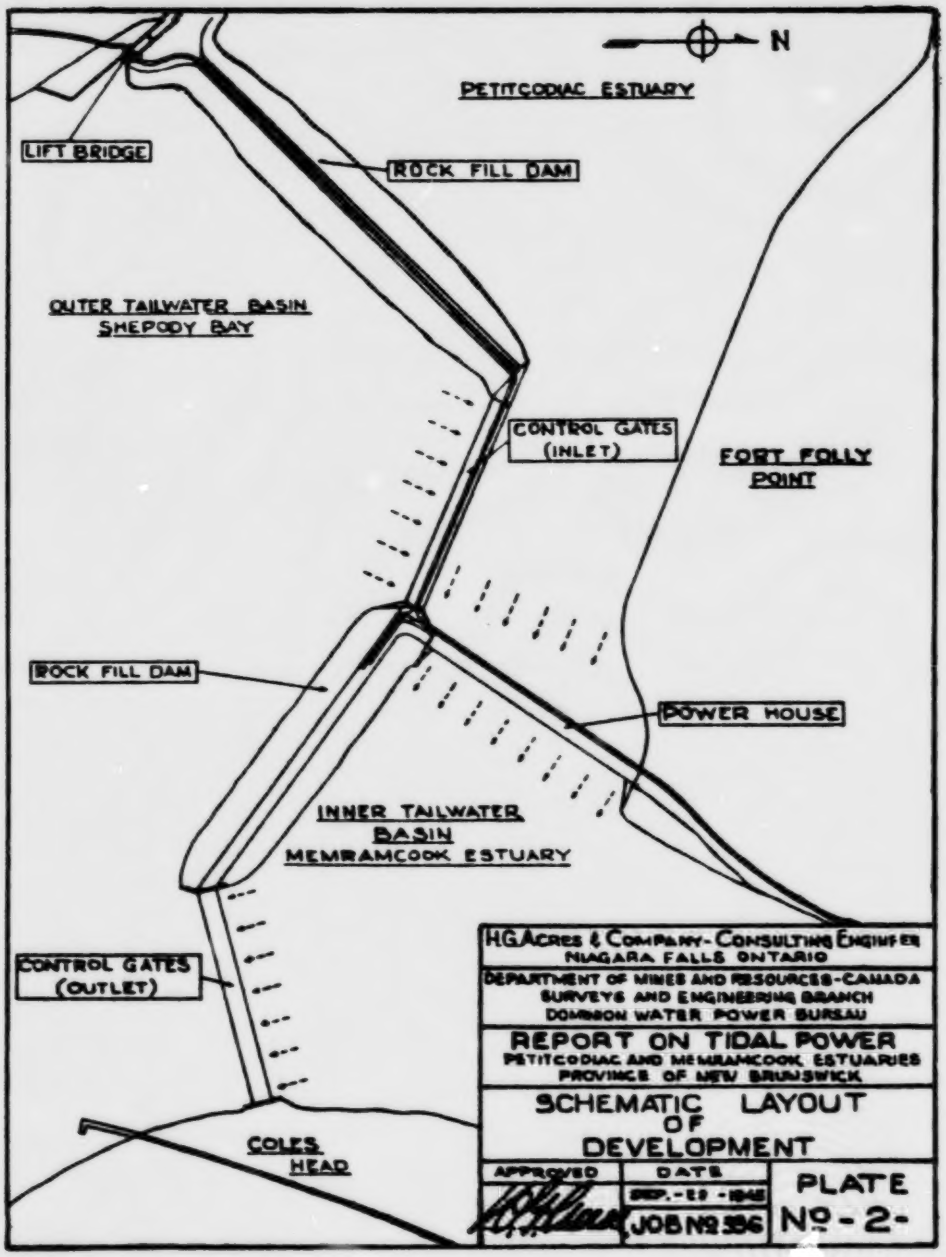
N
PETITCODIAC ESTUARY
LIFT BRIDGE
ROCK FILL DAM
OUTER TAILWATER BASIN
SHEPODY BAY
CONTROL GATES
(INLET)
FORT FOLLY
POINT
ROCK FILL DAM
POWER HOUSE
INNER TAILWATER
BASIN
MEMRAMCOOK ESTUARY
CONTROL GATES
(OUTLET)
COLES
HEAD
H.G. ACRES & COMPANY - CONSULTING ENGINEER
NIAGARA FALLS ONTARIO
DEPARTMENT OF MINES AND RESOURCES - CANADA
SURVEYS AND ENGINEERING BRANCH
DOMINION WATER POWER BUREAU
REPORT ON TIDAL POWER
PETITCODIAC AND MEMRAMCOOK ESTUARIES
PROVINCE OF NEW BRUNSWICK
SCHEMATIC LAYOUT
OF
DEVELOPMENT
APPROVED
DATE
SEP.-29-1945
JOB Nº 386
PLATE
Nº - 2 -

Figure C-2. Schematic Layout of Petitcodiac-Memramcook Development.

APPENDIX D

SUMMARY OF SOME TIDAL POWER INVESTIGATIONS WORLDWIDE

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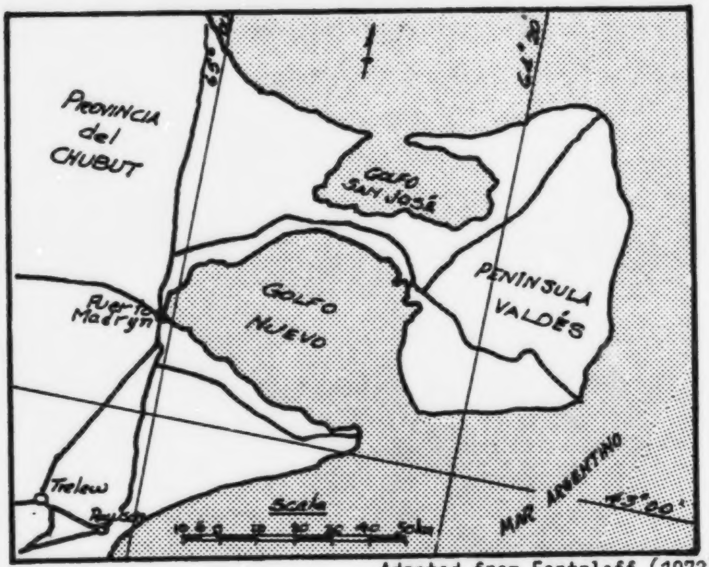
SUMMARY OF SOME TIDAL POWER INVESTIGATIONS WORLDWIDE

Argentina

The extraordinary sizes, proximity and unique configuration of two large gulfs, creating the Valdez Peninsula on Argentina's coast at about 43° south latitude, offers a possible and interesting site for a potentially economic tidal electric development, even though the tidal range is mediocre. A sketch of the region is shown in Figure D-1.


65°
64°30'
PROVINCIA del CHUBUT
GOLFO SAN JOSÉ
Puerto Madryn
GOLFO NUEVO
PENINSULA VALDÉS
Trelew
Rawson
Scale
10 5 0 10 20 30 40 50 km
MAR ARGENTINO
43°00'

Adapted from Fentzloff (1972)

Figure D-1. Configuration of Valdez Peninsula, Argentina

The tidal range is relatively low, approximately 8.5 m maximum, which would likely never justify the installation of a traditional single-basin plant such as described by Fentzloff (1972) for the San José Gulf only. However, the tidal flow at this location is absolutely unique and the peninsula's configuration is such that there is a tidal difference of almost a half-period on either side of a six km to eight km wide isthmus separating the two large gulfs.

The coastal morphology is apparently the cause of the peculiar propagation of the tidal current (Charlier, 1969). The Valdez Peninsula constitutes a rather extensive projection into the Atlantic Ocean and it requires about four hours for the tide to round the peninsula so that tides are delayed a half period between the northern coast of the isthmus (San Jose Gulf) and the southern coast (Nuevo Gulf). A level difference of almost 16 m results and this drop could be used to produce electricity by dredging a canal through the isthmus and installing a double-effect tidal electric plant with a probable installation of between 600 MW and 1200 MW at the canal's end of the San Jose Gulf.

A preliminary investigation revealed no insurmountable construction difficulty (Sogreah, 1959). Apparently, the isthmus shows remarkable uniformity both structurally and petrographically. The sediments are predominantly Tertiary and constitute a compact and impermeable strata, yet easily removed. The site is rather deserted and would be well-suited to the use of inexpensive methods to cut through the isthmus.

The unique tidal phenomenon has not yet been theoretically explained and there is the possibility that massive use would cause it to be greatly modified. Therefore, it would be absolutely necessary, prior to any major investigations of civil works, to understand the mechanics of the phenomenon. As of the mid-1970's there was only one permanent tide gauge along 300 km of coastline and records are available at only one or two other temporary gauge locations along the coast in the region for two periods of about one-month each. In the light of current tidal analysis techniques, this would no longer seem adequate. In addition, measurements of currents and tidal amplitudes in the open sea would be necessary, at least to the limit of the continental shelf.

Australia

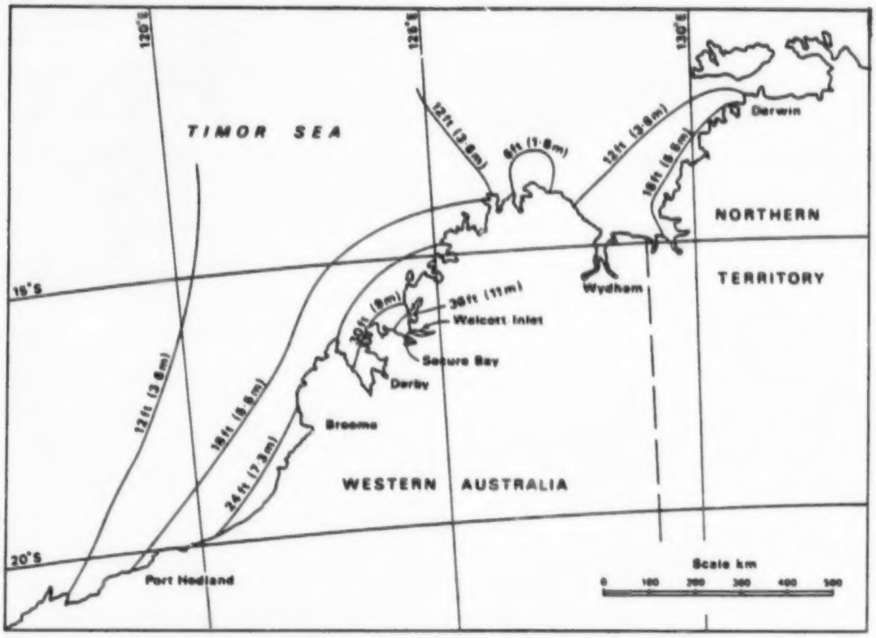
The potential of the tidal power sites on the uninhabited Kimberley Coast of the northern shores of Western Australia have been given cursory or preliminary study since the late 1950's. There are a number of possible sites which, if feasible, would have a large aggregate potential. Lewis (1963) reviewed the resources of the region and identified over 40 bays and estuaries in this rugged coastline where the mean spring tide ranges from about 5 m to about 11 m.

Two adjacent estuaries, Walcott Inlet and Secure Bay (Figures D-2 and D-4), with surface areas of 280 km^2 and 65 km^2, respectively, appear to have the most favourable configurations enhanced by their tidal ranges of up to 11 m (mean springs). The 1965 report of a study commissioned by the Government of Western Australia, indicated that Secure Bay was the better of the two sites primarily because it offered a more appropriate scale for a first-stage development and a less severe tidal closure than Walcott Inlet. Table D-2 indicates the probable values of the parameters for development of these inlets as single-basin, ebb-generation schemes.

Table D-1

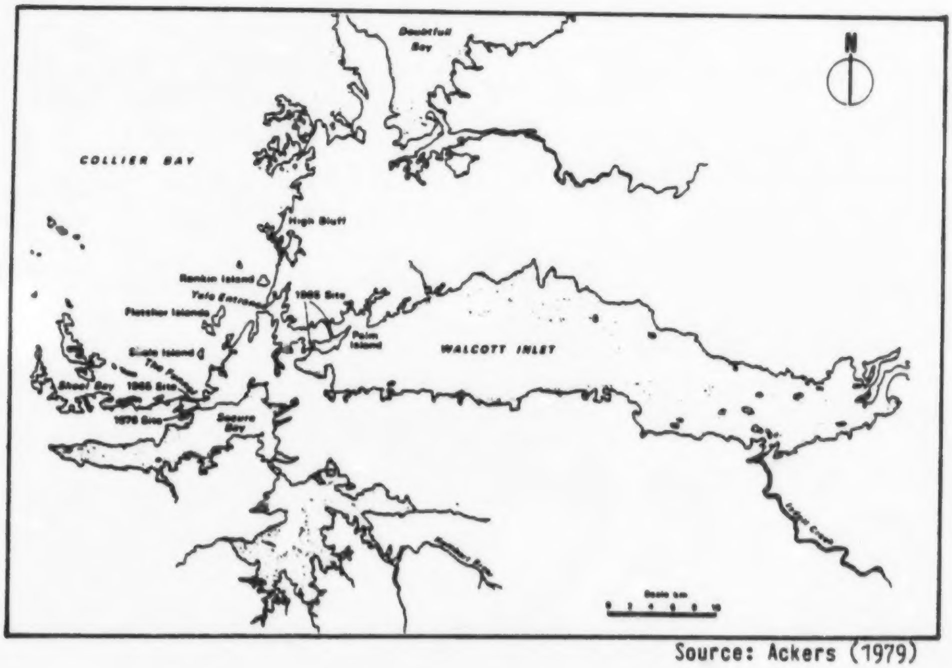
Probable Development Characteristics at Secure Bay and Walcott Inlet

Item	Secure Bay	Walcott Inlet
Installed capacity	570 MW	1250 MW
Average annual energy output	1650 GWh	3940 GWh
Length of tidal dam	1870 m	2500 m
Basin area at max. tide	180 km^2	415 km^2
No. of bulb turbines (7.35 m dia.)	30	60
Sluice gate area	6680 m^2	13,800 m^2
Excavation volume	$4.3 \times 10^6 m^3$	$58 \times 10^6 m^3$


120°E
126°E
130°E
TIMOR SEA
12ft (3·6m)
6ft (1·8m)
12ft (3·6m)
Darwin
18ft (5·5m)
NORTHERN
TERRITORY
15°S
Wydham
36ft (11m)
30ft (9m)
Walcott Inlet
Secure Bay
Derby
Broome
12ft (3·6m)
18ft (5·5m)
24ft (7·3m)
WESTERN AUSTRALIA
20°S
Port Hedland
Scale km
0
100
200
300
400
500

Source: Ackers (1979)

Figure D-2. Kimberley coastline, northwest Australia.


Doubtful Bay
N
COLLIER BAY
High Bluff
Rankin Island
Yule Entrance
1966 Site
Fletcher Islands
Palm Island
WALCOTT INLET
Slate Island
Shoal Bay
1966 Site
1976 Site
Secure Bay
Scale km
0
2
4
6
8
10

Source: Ackers (1979)

Figure D-3. Walcott Inlet and Secure Bay.

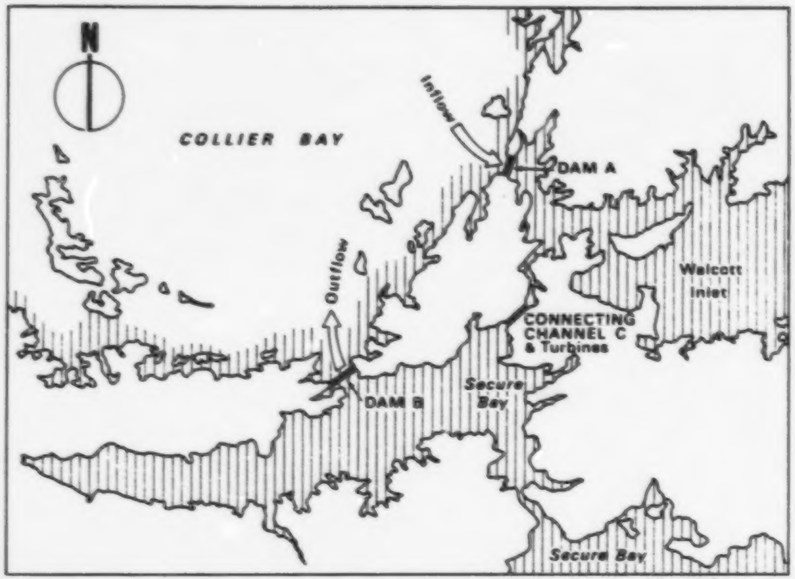
Construction of the main works was proposed to be carried out in the dry behind cofferdams.

Saunders (1974) reviewed again the tidal potential of these sites and updated the estimated costs. He indicated that the construction time would have to be shortened by several years, perhaps by the use of floated-in caissons with pre-installed equipment, if a tidal electric plant at Secure Bay were to be competitive with fossil-fuel generation under Australian conditions.

A further study was undertaken in 1976 (Ackers, 1979) with the main objective limited to civil engineering aspects, and the main task being to study the feasibility of closing the estuaries by new techniques that could speed the construction of the permanent works and reduce costs, compared to the 1965 proposals. The use of floated-in caissons was shown to be feasibile, both hydraulically and structurally, and to reduce the civil engineering costs by about 45%; permanent caissons may also be used to effect closure.

Future investigations may well indicate the feasibility of developing a two-basin scheme using Walcott Inlet as the high-level basin and Secure Bay as the low-level basin, as indicated in the sketch of Figure D-4.

Because the area is virtually uninhabited and there is no existing development in these estuaries, few problems of estuary management are anticipated but an evironmental appraisal would be required if there were a prospect of proceeding with a tidal power scheme. One of the main problems is the lack of an established local energy market but it is possible that mineral and other developments in northwestern Australia would be stimulated by a viable, available energy source. Extensive pre-feasibility investigations would, however, be required in order to justify a costly, definitive feasibility study.


N
COLLIER BAY
Inflow
DAM A
Walcott Inlet
Outflow
CONNECTING CHANNEL C & Turbines
DAM B
Secure Bay
Secure Bay

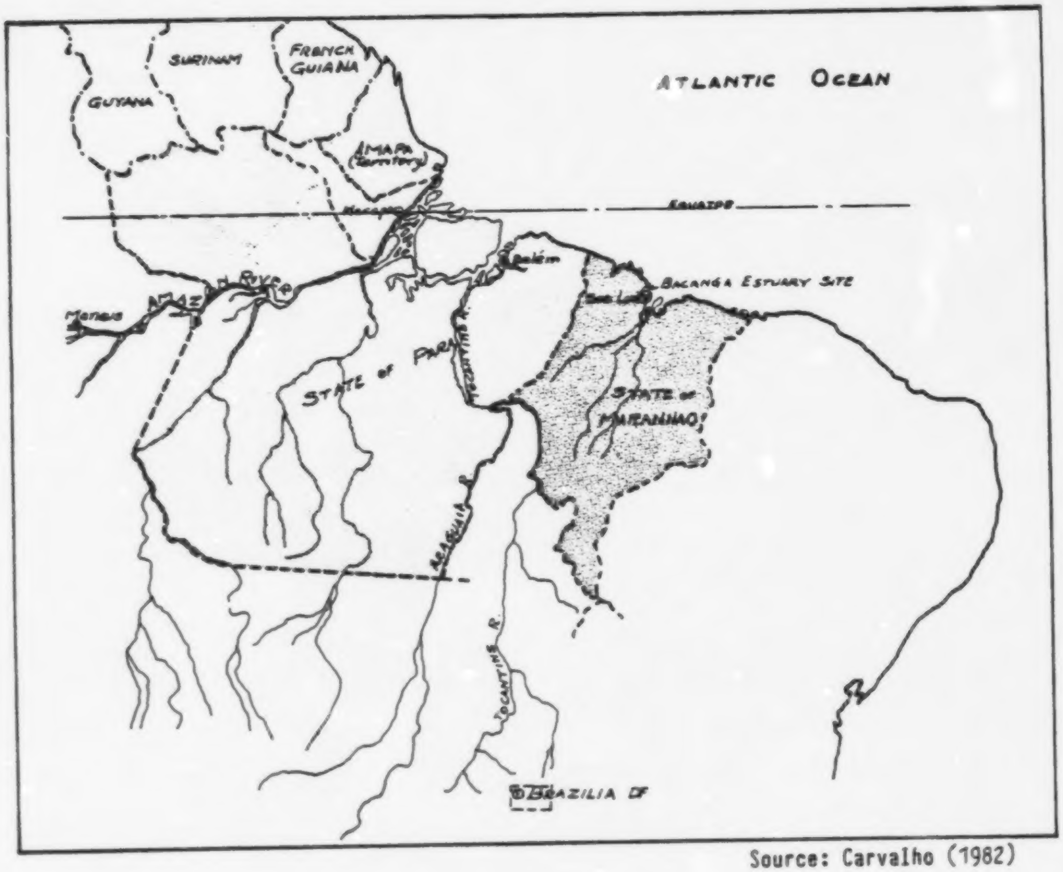
Source: Ackers (1979)

Figure D-4. Layout of Potential Double-basin Scheme, Walcott Inlet-Secure Bay.

Brazil

In 1979-80 ELETROBRAS commissioned a survey of the tidal power potential of the Maranhao-Para-Amapa coast of Brazil (refer Figure D-5) forty-three sites were identified and field reconnaissance carried out at each. Thirteen of the sites were selected for preliminary study. The mean tidal ranges along the northeast coast of Brazil range from about 5 m in Maranhao and Para provinces to about 8 m in Amapa where a maximum range of 13.5 m has been recorded in Maraca Harbour (Carvalho,1982).

The total installed capacity at the 43 sites has been estimated at 27,000 MW with a potential annual energy production of 72 TWh; equivalent to a consumption of 432,000 bbl/day of petroleum. The unit cost of installation was estimated to vary between US$1,000-$1,500/kW (1980 price levels).


SURINAM
FRENCH GUIANA
GUYANA
ATLANTIC OCEAN
AMAPA (Territory)
Macapa
EQUATOR
Belém
BACANGA ESTUARY SITE
Sao Luis
Manaus
AMAZON RIVER
STATE OF PARA
TOCANTINS R.
STATE OF MARANHAO
ARAGUAIA R.
TOCANTINS R.
BRAZILIA DF

Source: Carvalho (1982)

Figure D-5. Amapa-Para-Maranhao coastline of Brazil.

A design was prepared for a pilot plant in the Bacanga estuary near Sao Luis (located on Figure D-5). The pilot project would make use of an existing dam and spillways for an installation of about 5,000-9,000 kW in two bulb turbo-generators capable of double-effect action, both generating and pumping.

Canada

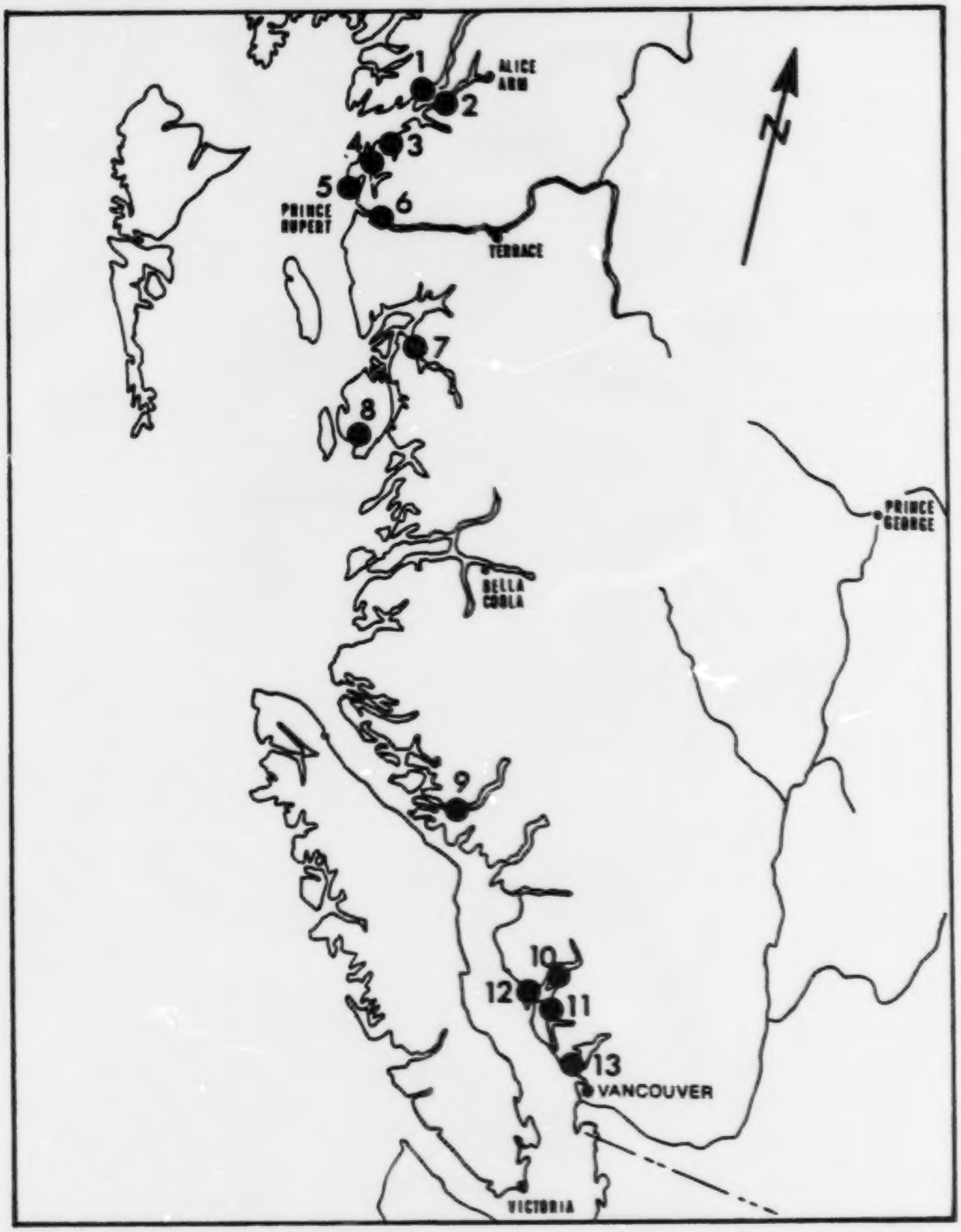
In addition to the Bay of Fundy, there are several potential tidal power sites on the western and northern coasts of Canada offering possibilities for development.

The British Columbia Hydro and Power Authority (1979) made a cursory examination of thirteen potential sites on British Columbia's coast (refer Figure D-6) where the mean tidal range varies from 3.5 m to over 5 m.

For the purpose of estimating costs for typical tidal electric developments on the B.C. coast, the two most attractive sites, in Observatory Inlet (Site 1) and in Sechelt Inlet (Site 11), from the inventory in Table D-2 were given relatively more detailed study. Possible project layouts for the Observatory and Sechelt Inlets are outlined in Figures D-7 and D-8, respectively.

These two sites could provide about 2200 GWh annually but the unit cost of energy would be almost an order of magnitude greater than other generation options available to the Authority. There is, therefore, no incentive to pursue detailed studies, although a watching brief will likely be maintained to reassess periodically the tidal generation option.

The geographical configuaration of Ungava Bay, along the Hudson Straits, with its average tide ranges of 7 m to 8.5 m offers sites with a total potential installation of about 5500 MW (Godin, 1974). The major


1
ALICE ARM
2
3
4
5
PRINCE RUPERT
6
TERRACE
N
7
8
PRINCE GEORGE
BELLA COOLA
9
10
12
11
13
VANCOUVER
VICTORIA

Source: B.C. Hydro (1979)

Figure D-6. Coastline of British Columbia showing location of potential tidal power sites.

Table D-2

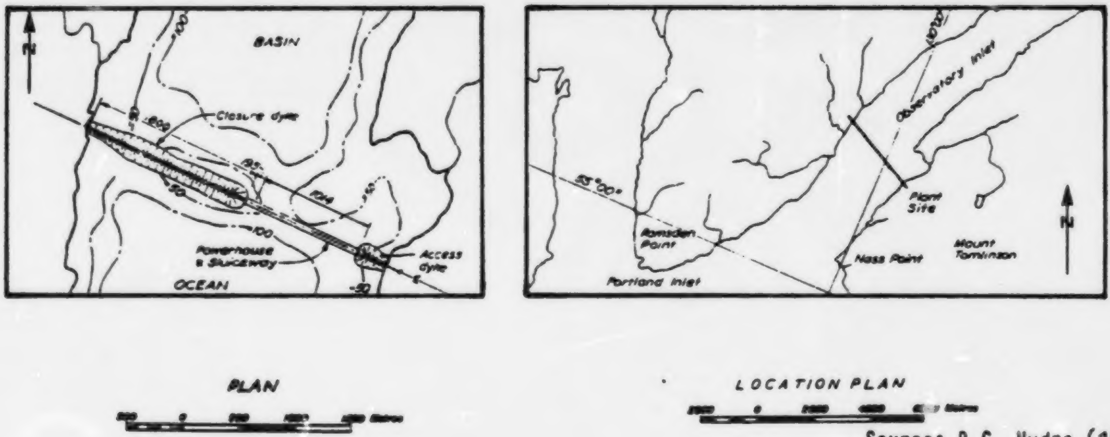
Potential Tidal Power Sites in British Columbia

Site	Mean Tidal Range	Basin Area	Installed Capacity	Annual Energy Output
	m	Km^2	MW	GWh
1. Portland Canal	5	209	738	2264
2. Observatory Inlet	4.7	212	662	2030
3. Khutzeymateen Inlet	4.7	27	85	259
4. Work Channel	4.7	80	250	766
5. Prince Rupert	4.9	10	34	104
6. Skeena River	5.3	31	123	377
7. Gardner Canal	4.2	171	426	1307
8. Laredo Inlet	3.5	66	114	350
9. Knight Inlet	3.8	232	474	1452
10. Jervis Inlet	3.5	158	249	763
11. Sechelt Inlet	3.5	106	54	167
12. Jervis and Sechelt	3.5	430	677	2075
13. Howe Sound	3.3	282	395	1210

difficulties, even before contemplating the developments themselves, are the distances, exceeding 1500 km, to major load centres and the lack of communications and development in this hinterland of Canada.

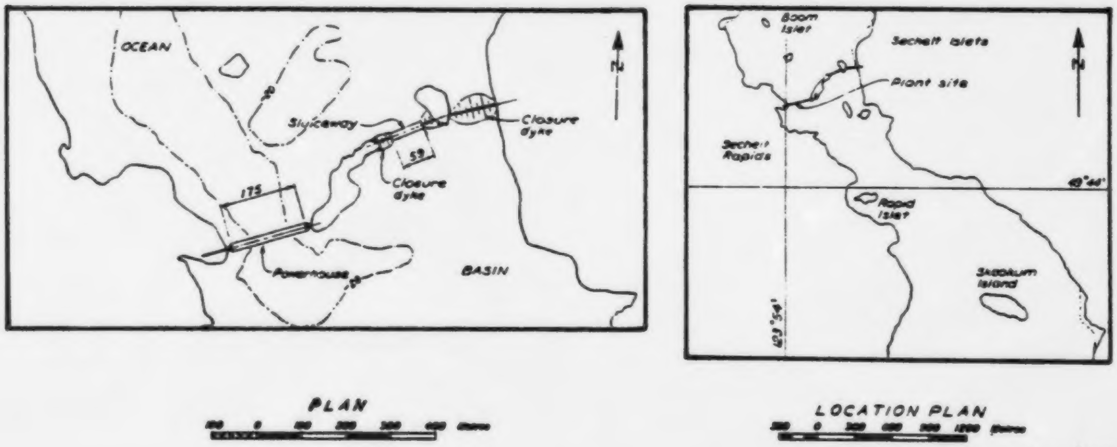
France

With the commissioning of the LaRance tidal power project in November 1966, official interest in further tidal power development in France waned. However, in the current quest for renewable energy sources, tidal power is now seen in a different way. Several hydraulically-linked double-basin schemes along the Contentin Peninsula, embracing the Iles Chausey and Mont St. Michel Bay, are under consideration. Such a project would, in addition to altering the basin's established ecosystems and changing the landscape, affect a very large population making a living from the sea (e.g. fishing and oyster and


BASIN
Closure dyke
Powerhouse & Sluiceway
Access dyke
OCEAN
PLAN
Observatory Inlet
Plant Site
Ramsden Point
Nass Point
Mount Tomlinson
Portland Inlet
55°00'
LOCATION PLAN

Source: B.C. Hydro (1979)

Figure D-7. Possible development layout for Observatory Inlet.


OCEAN
Sluiceway
Closure dyke
Closure dyke
175
59
Powerhouse
BASIN
PLAN
Boom Islet
Sechelt Islets
Plant site
Sechelt Rapids
Rapid Islet
Skookum Island
LOCATION PLAN

Source: B.C. Hydro (1979)

Figure D-8. Possible development layout for Sechelt Inlet.

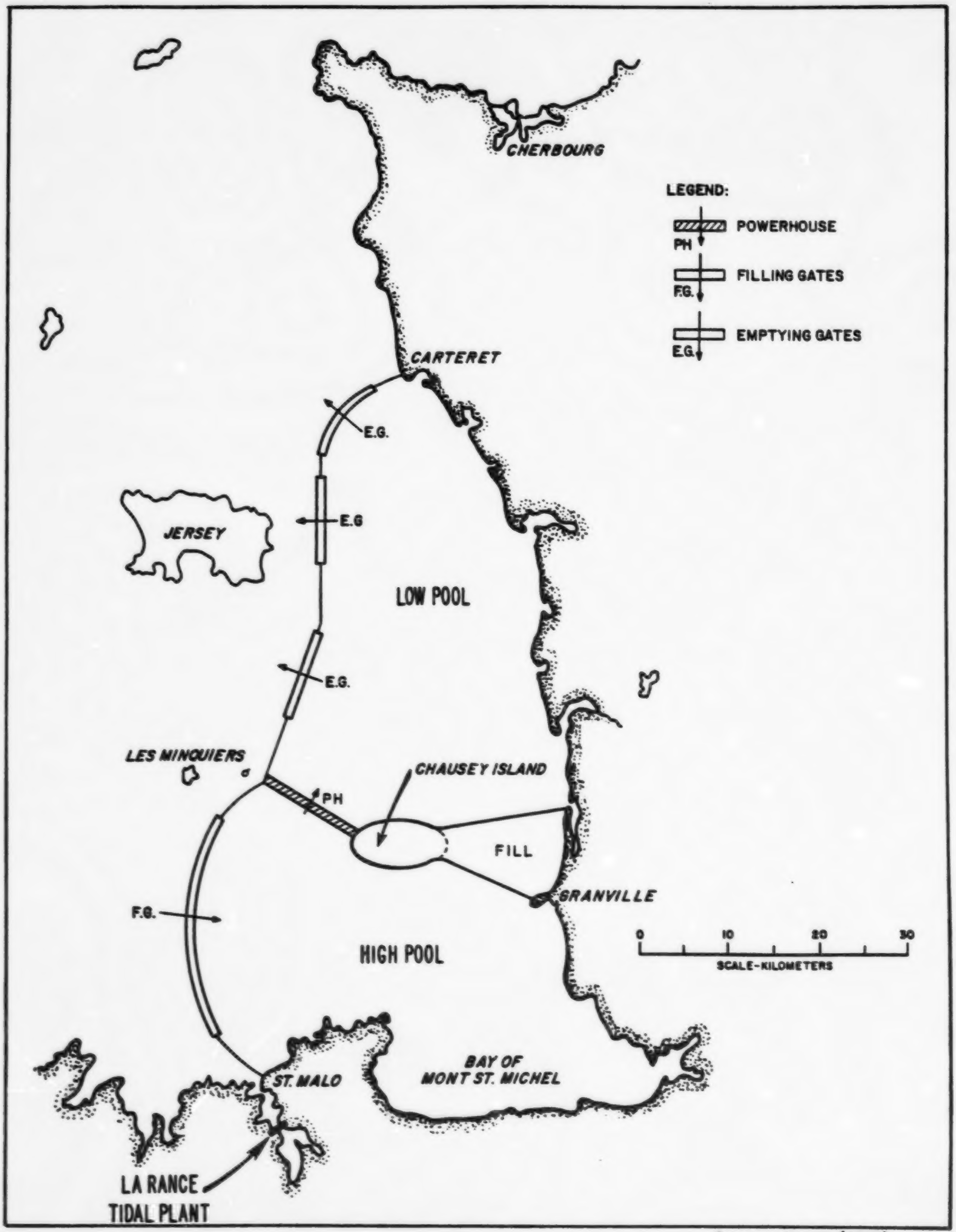
shellfish breeding) and from tourism. A first step, therefore, has been to initiate the appropriate studies to assess environmental impacts and effects on regional economic development.

The Iles Chausey tidal project (Bonnefille, 1978) has many possible arrangements and sizes with estimated installed capacities ranging from 6000 MW to 15000 MW depending upon the characteristics of the proposed layout. One of the extensive layouts is shown in Figure D-9. Although preliminary studies were initiated by Electricité de France in 1980, it should be borne in mind that this electrical utility was, at the time, embarked on a very large nuclear construction programme, totalling about 29000 MW and facing a major financing problem (Cotillon, 1979). The results of those studies are not available.

India

There are relatively large tidal power potentials available in the gulfs of Kutch and Cambay in Gujarat, and possibilities of small-scale developments in the Sunderbans area of West Bengal. These regions are in a part of India where energy is scarce and expensive, with dependence on coal imported from East Bengal.

In 1975, a preliminary assessment of the technical and economic feasibility of developing tidal power projects at suitable locations was sponsored by the United Nations (1975). The results of the assessment suggested two single-basin schemes to develop the energy potential of the two esturaries in Gujarat (Subrahmanyan, 1978). The size of the installation in the Gulf of Cambay would range from about 5000 to 7000 MW, while that to exploit the energy of the Gulf of Kutch would be about 1200 MW. A double-basin scheme was also proposed for the latter with an installation of about 600 MW. However, based on preliminary estimates, the cost of energy generation by the two-basin alternative would be almost double that from the single-basin schemes but it would provide some firm capacity and energy.


CHERBOURG
LEGEND:
PH POWERHOUSE
F.G. FILLING GATES
E.G. EMPTYING GATES
CARTERET
E.G.
JERSEY
E.G
LOW POOL
E.G.
LES MINQUIERS
CHAUSEY ISLAND
PH
FILL
GRANVILLE
F.G.
HIGH POOL
0
10
20
30
SCALE-KILOMETERS
BAY OF
MONT ST. MICHEL
ST. MALO
LA RANCE
TIDAL PLANT

Source: Wayne (1977)

Figure D-9. A two-basin scheme for Iles Chausey site.

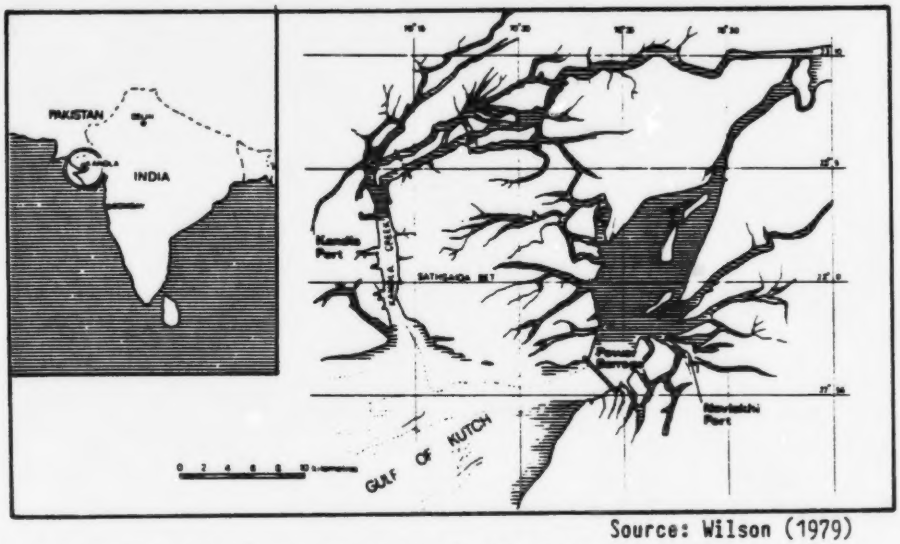
Table D-3

Tidal Characteristics in Gulfs of Cambay and Kutch

Location	Spring Range m	Neap Range m	Average Range m
Bhavnagar (Gulf of Cambay)	10.29	3.6	7.0
Navlakhi (Gulf of Kutch)	7.17	3.74	5.45
Kandla (Gulf of Kutch)	6.32	3.68	5.00

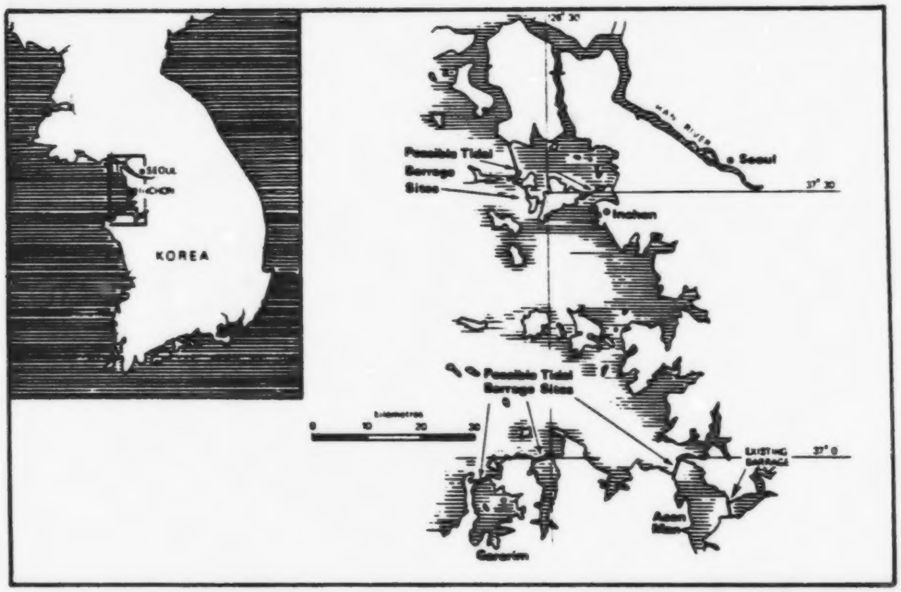
The problem of integrating, with the electrical power system of Gujarat, the intermittent output of the large single basin schemes, particularly those for the Gulf of Cambay, would likely pose an unsurmountable problem at this time. Very extensive civil works would be required for the schemes suggested. In view of the problems posed by the magnitudes of these schemes, an alternative development has been suggested (Subrahmanyan, 1978; Wilson, 1979) which would involve a power barrage at the narrows, seaward of Navlakhi Port (Figure D-10) with two small, subsidiary structures to prevent impounded waters in the basin flowing through Kandla Creek. The basin area has been estimated to be about 260 km^2 with a probable plant installation of 600 MW made up of about 30, 9 m diameter turbines. The barrage would be formed of powerhouse and sluiceway caissons and a rock-fill section. An attractive feature of this arrangement and degree of installation is that it would be possible to convert it to a two-basin alternative by judicious choice of generation equipment and by initially designing and locating the civil works to accommodate such an extension of the scheme.

A feasibility study to exploit the energy potential of the Gulf of Kutch was launched in 1982 and was scheduled for completion in March


PAKISTAN
INDIA
GULF OF KUTCH
SATHSAIDA BET
Port
Navlakhi Port
0 2 4 6 8 10

Source: Wilson (1979)

Figure D-10. Proposed inner Kutch ebb-generation scheme.


SEOUL
KOREA
HAN RIVER
Seoul
Possible Tidal Barrage Sites
Inchon
37° 30
Possible Tidal Barrage Sites
0 10 20 30
EXISTING BARRAGE
37° 0
Garorim

Source: Wilson (1979)

Figure D-11. Potential tidal power sites off Kyonggi Bay, Korea.

1987. An international symposium on tidal power development sponsored by the Central Electricity Authority of India is to be held in New Delhi in February 1988. It is assumed that this will be an opportunity for an open discussion of the proposals arising out of the feasibility study.

The tidal power possibilities in the Sunderbans region are small-scale, generally about 2 MW, although it is reported that one site may support a 15 MW installation.

Korea

The indigenous energy sources of Korea are quite limited. The major source of energy is oil, which must be imported. Under the current volatile world energy situation attention has turned to the exploitation of the potential tidal energy offered by the many bays and inlets along the west coast of Korea, notably Incheon, Asan, Garolim and Cheonsu Bays which open onto the Yellow Sea. In these estuaries, the mean tidal ranges are about 5.7, 6.1, 4.8 and 4.5 m, respectively, which has sparked studies since the 1940's to harness their energy.

In 1977, a Phase I study was commissioned to: evaluate the tidal power potential on the west coast of Korea, to determine the priority of sites and to recommend a site for detailed feasibility study for Phase II of the tidal power program undertaken by the Government of Korea.

The report of the Phase I study, which concentrated on tidal power aspects only, ingnoring multi-purpose considerations, recommended Asan Bay, in which two sites were proposed for further detailed study (Song, 1978). The smaller of the projects in this Bay was shown to be marginally economic at the time, with an installation of about 450 MW and an annual energy output of 1345 GWh. Figure D-11 shows the locations of possible barrage sites in the estuaries opening off Kyonggi Bay.

Subsequently, it was decided that the Phase II technical and economic feasibility studies would be carried out for a tidal electric plant at the mouth of Garolim Bay. The Phase II study, which was completed in 1981, resulted in a recomended scheme for a tidal electric plant equipped with 24 turbo-generators of 20 MW each in a barrage which would control a basin of about 100 m^2. The barrage would have a total length of about 2.1 km with the powerhouse and sluiceway sections being constructed of precasd, floated-in caissons. The tides of Garolim Bay are of the semi-diurnal type with a large diurnal inequality and spring and mean tide ranges of 7.9 m and 4.8 m, respectively. At a discount rate of 9% and a plant completion date of 1988, the benefit-cost ratio was only 1.189 (SOGREAH, 1981). A tidal power station had been included in the Korean 5-year plan commencing 1982 for operation by 1986, but was not undertaken. The results of a subsequent study, completed in 1986, is discussed in the main report beginning on page 20.

United Kingdom

Interest in the possibility of tidal electric power plants began well over a half century ago, particularly with regard to harnessing the high tides of the Severn Estuary which have a mean range of 8.5 m. Renewed, world-wide and national interest in tidal power, inter alia, resulted in the U.K. Government establishing a Severn Barrage Committee in 1978. The report of this Committee was issued in mid-1981. The results of that study and subsequent activities are summarized in the main report, pages 23 through 30 .

Other potential sites in the United Kingdom which have received cursory, or very preliminary, scrutiny are: Solway Firth (mean tidal range of 5.6 m); Morecombe Bay (mean tidal range, 6.0 m); and Wash (mean tidal range, 4.9 m). The total practical annual output from these three estuaries, as single-basin ebb-generation schemes, would be about 7 TWh (Ad Hoc Working Party, 1978). The location of the major sites in the UK are given in Figure D-12.

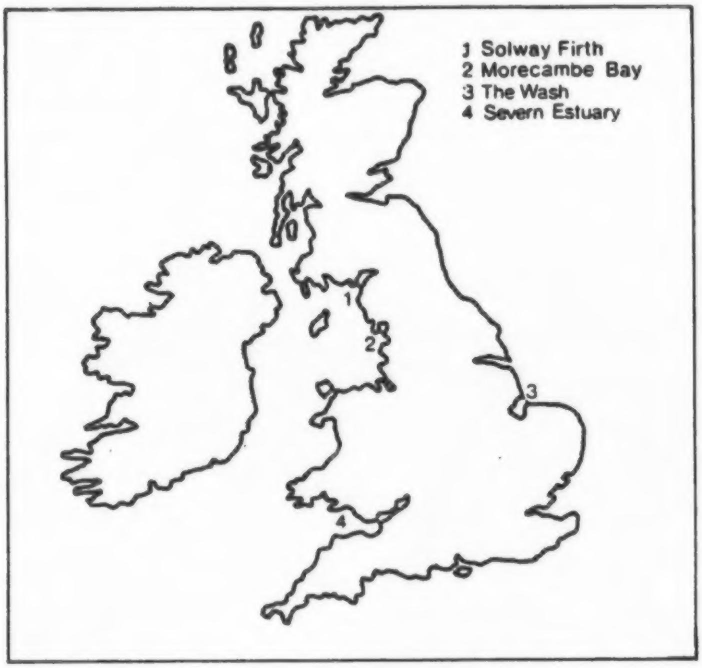
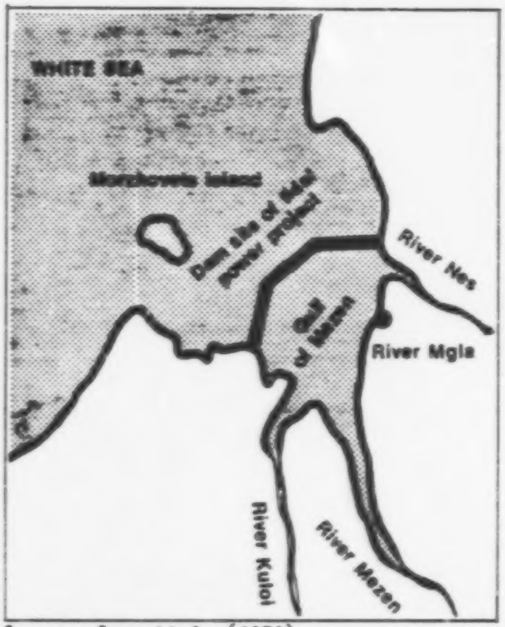


Figure D-12. Potential tidal power sites in the United Kingdom.

U.S.S.R.

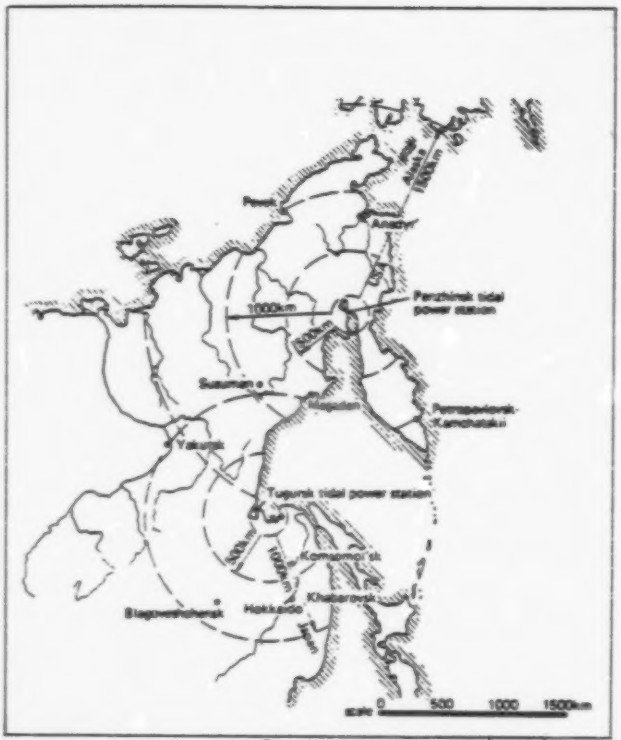
The basic objective of building the Kislaya Guba tidal power station was to test construction methods and materials proposed for the eventual and most cost-effective development of the large potential sites on the coasts of the White and Okhotsk Seas (Figure D-13).

The USSR has under active consideration (Bernshtein, 1979 and 1985) two projects for Lumbov Bay and the Gulf of Mezen in the White Sea. The Lumbov Bay is on the coast of the Kola Peninsula on the boundary between the Barents and White Seas and exhibits spring tides of 7 m. The estuary would be cut off from the sea with two barrages, 2.8 km and 5 km in length. One barrage would contain the necessary 32 sluiceway


WHITE SEA
Morzhovets Island
Dam site of tidal power project
River Nes
Gulf of Mezen
River Mgla
River Kuloi
River Mezen

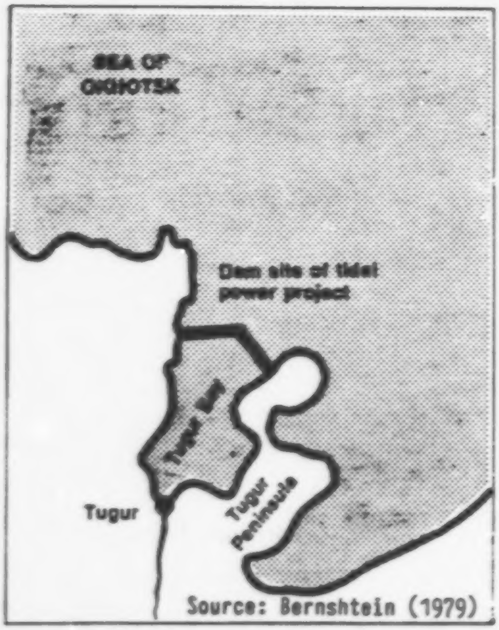
Source: Bernshtein (1979)

Figure D-14. Site of Mezen tidal power project.


Alaska
1800km
Pevek
Anadyr
Penzhinsk tidal power station
1000km
500km
Susuman
Magadan
Petropavlovsk-Kamchatskii
Yakutsk
Tugursk tidal power station
500km
1000km
Komsomol'sk
Khabarovsk
Blagoveshchensk
Hokkaido
Japan
scale 0 500 1000 1500km

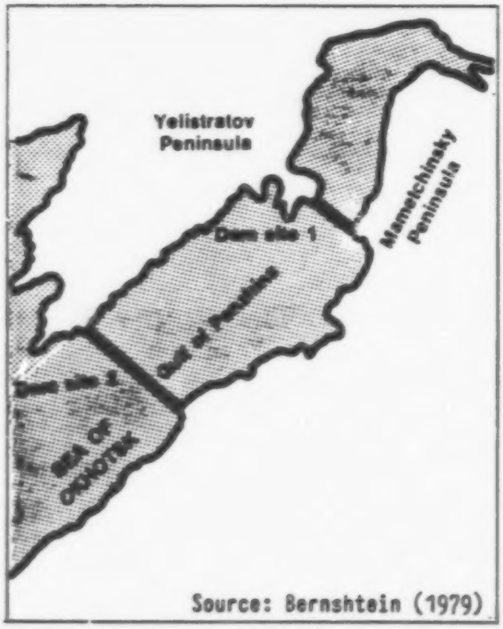
Source: Bernshtein (1974)

Figure D-13. Location of tidal power sites Sea of Okhotsk.


SEA OF OKHOTSK
Dam site of tidal power project
Tugur Bay
Tugur
Tugur Peninsula

Source: Bernshtein (1979)

Figure D-15. Site of Tugur Bay tidal power project.


Yelistratov Peninsula
Mametchinsky Peninsula
Dam site 1
Gulf of Penzhina
Dam site 2
SEA OF OKHOTSK

Source: Bernshtein (1979)

Figure D-16. Alternative sites for Penzhina tidal power project.

openings and the other, the powerhouse, with 60, 7.5 m diameter turbines. The expected annual output is 100 GWh. However, with an average tidal range of only 4.2 m and the relatively small area of the bay, it is not likely to be considered in the foreseable future. A larger development is proposed for the Gulf of Mezen which would feature a 92.9 km barrage to cut off the eastern part of the Gulf. As shown (Figure D-14), the barrage will be in the form of a seaward trapezoidal projection that will provide room for the 17 km long plant facilities at depths requiring no excavation. Since there are tides of up to 9 m in the 2,280 sq.km. reservoir, the capacity of the project would require 200 caissons for 800 turbo-generator units with 7.5 m diameter turbines, giving a 50 TWh energy output.

The feasibility of tidal power plants in Tugur Bay and Gulf of Penzhina in the Sea of Okhotsk is also under consideration. Tugur Bay has tides of up to 8 m with an average tidal range of 4.74 m and could yield up to 27 TWh (Figure D-15). The 13.5 m tides in the Gulf of Penzhina are comparable to those in the Severn Estuary and the Bay of Fundy. Two possibilities are being explored to develop the energy potential of this gulf (Figure D-16). The whole of the Gulf could be isolated by means of a barrage 72 km long and up to 60 m height to form a reservoir 20,530 sq.km. in area. With a mean tidal height of 6.9 m, it would be possible to erect a tidal plant with 87 GW capacity for an annual output of 200 TWh. An alternative would involve a 31.5 km long barrage, in depths up to 25 m, to form a reservoir 6,788 sq.km. The latter proposed layout would have an installed capacity of 20.4 GW and produce some 79 TWh annually. Such large developments would, of course, require extensive investigations and substantial international cooperation. Complex problems stemming from the geographical locations and hostile climatic environments are expected, but Bernshtein (1979) suggests that the marine and hydraulic machinery technologies should be adequate to the challenge by the time such developments are on the drawing board. It is planned to construct an intermediate-sized prototype scheme, with two 19 MW turbines, in Kola Bay (where Murmansk is situated). A caisson with the two turbo-generators will be part of an 800 m long dam in the bay (see Figure B-5). The turbine will be the prototype machines for the Mezen scheme although the average tidal rante in Kola Bay is only about one-half of that in the Gulf of Mezen.

United States

International Passamaguoddy tidal power project: More than a half-century ago, plans were promoted by United States interests for a two-basin scheme, involving the Canadian territory of Passamaquoddy Bay, to utilize the tides of Passamaquoddy and Cobscook Bays near the entrance to the Bay of Fundy. The tides range from 3.4 m to 7.8 m with an average tide of 5.5 m. The project area contains a number of islands thereby offering a number of alternate ways of constructing a two-pool tidal development.

At least two small tidal grist mills operated in the area prior to 1800 and tidal hydro-electric projects in the area have been under investigation for the last 50 years. In the early 1920's Dexter P. Cooper initiated a large scale investigation of an international project but the Canadian Biological Board reported adversely on the scheme in 1929 because of its effect on fisheries. Permits and charters for the study expired that year. Dexter P. Cooper Inc. then applied for a licence for a project wholly within the United States, but this was denied in 1935 as the United States Government had undertaken a tidal project in the same area.

In January 1935 the American Passamaquoddy Bay Tidal Power Commission recommended construction of a $30 million project which would be wholly within the United States. The project was approved for construction in 1935 under authority of the Emergency Relief Appropriation Act. The Corps of Engineers prepared cost estimates which placed the project in the $60 - $70 million range. In just over a year of active work nearly $7 million was spent acquiring the assets of Dexter

P. Cooper Inc., making engineering studies and construction of three tidal dams. No further appropriations were made by the U.S. Congress.

On November 9, 1948 the Governments of Canada and the United States requested the International Joint Commission (IJC) to review existing plans for tidal developments in the project area, to determine the scope and cost of an investigation necessary to establish whether these or any other plans were practicable or desirable and to report its recommendation for cost sharing of further investigations. The report submitted in 1950 suggested that a study to determine economic feasibility would cost $3.6 million and would take 18 months to complete. (The estimate was later reduced to $3 million.)

In 1956 the IJC was given a reference to "... determine the estimated cost of developing the international tidal power potential of Passamaquoddy Bay ... and determine whether such cost would allow hydroelectric power to be produced at a price which is economically feasible". The study was also to consider the effect of the project on local and national economies, fisheries, etc. The IJC Board which carried out the studies reported in 1959 on an hydraulically-linked, two-basin scheme (Figure D-17) with an installed capacity of 300 MW and a dependable capability of 95 MW. The Board noted, inter alia, that:

> "Assuming an equal division of power output and of first costs between the United States and Canada, construction of the tidal power project with all of Rankin Rapids [proposed hydroelectric project on the Saint John River in Maine] as auxiliary is not an economically justified project for Canada."
>
> "The Passamaquoddy tidal project and Rankin Rapids combination, if built entirely by the United States at an interest rate of 2 1/2 percent, is economically justified."

A 1963 report by the U.S. Department of the Interior recommended construction of a peaking project at Passamaquoddy (1 million kilowatts of installation as compared to 300,000 kilowatts in the IJC Report) and

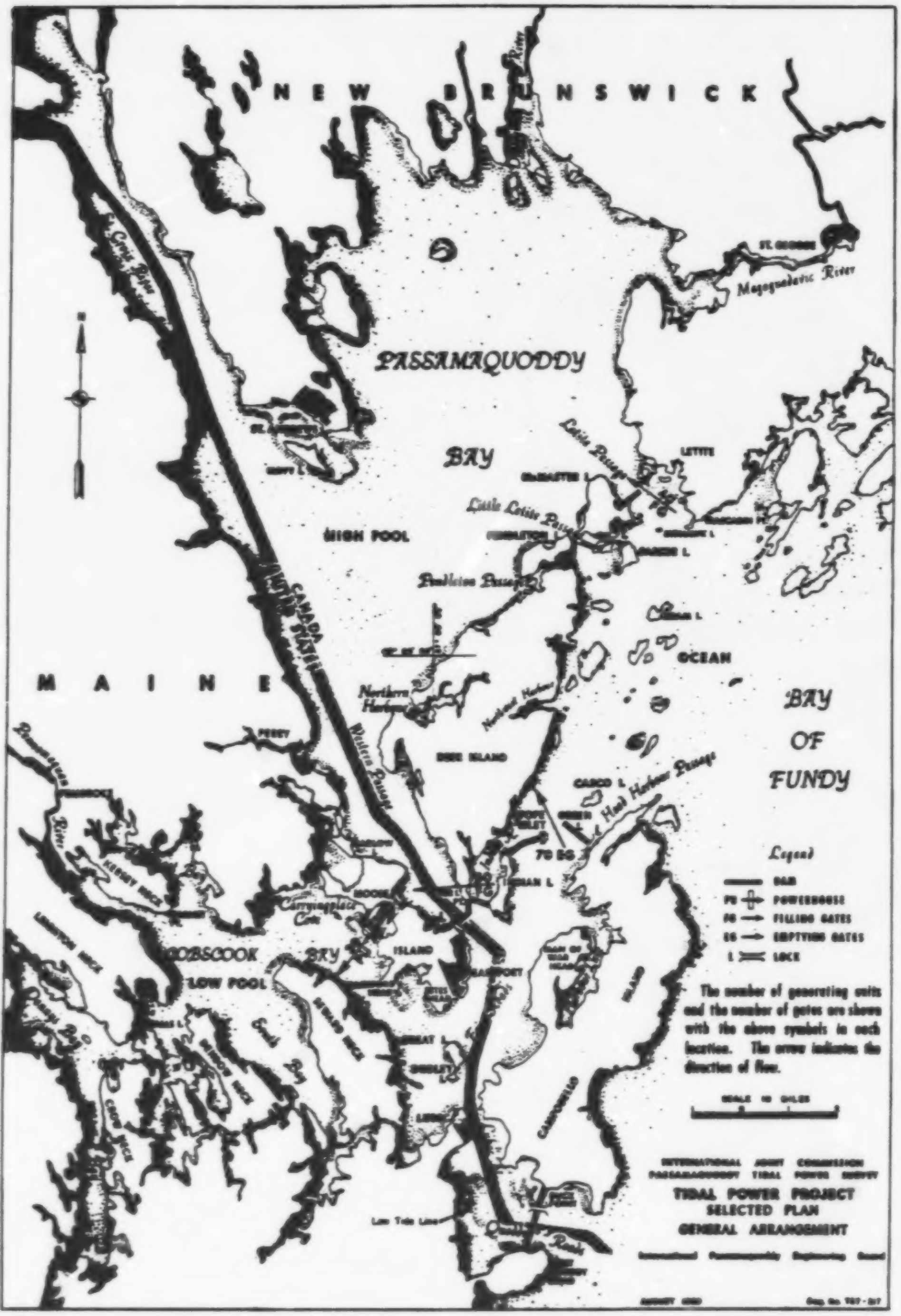

NEW BRUNSWICK
PASSAMAQUODDY
BAY
HIGH POOL
Magaguadavic River
ST. GEORGE
LETITE
Letite Passage
Little Letite Passage
Pendleton Passage
OCEAN
BAY
OF
FUNDY
M A I N E
Northern Harbour
DEER ISLAND
Western Passage
Head Harbour Passage
INDIAN I.
Carryingplace Cove
COBSCOOK
BAY
LOW POOL
EASTPORT
CAMPOBELLO
ISLAND
Low Tide Line
Legend
DAM
PH POWERHOUSE
FG FILLING GATES
EG EMPTYING GATES
L LOCK
The number of generating units and the number of gates are shown with the above symbols in each location. The arrow indicates the direction of flow.
SCALE IN MILES
INTERNATIONAL JOINT COMMISSION
PASSAMAQUODDY TIDAL POWER SURVEY
TIDAL POWER PROJECT
SELECTED PLAN
GENERAL ARRANGEMENT
International Passamaquoddy Engineering Board

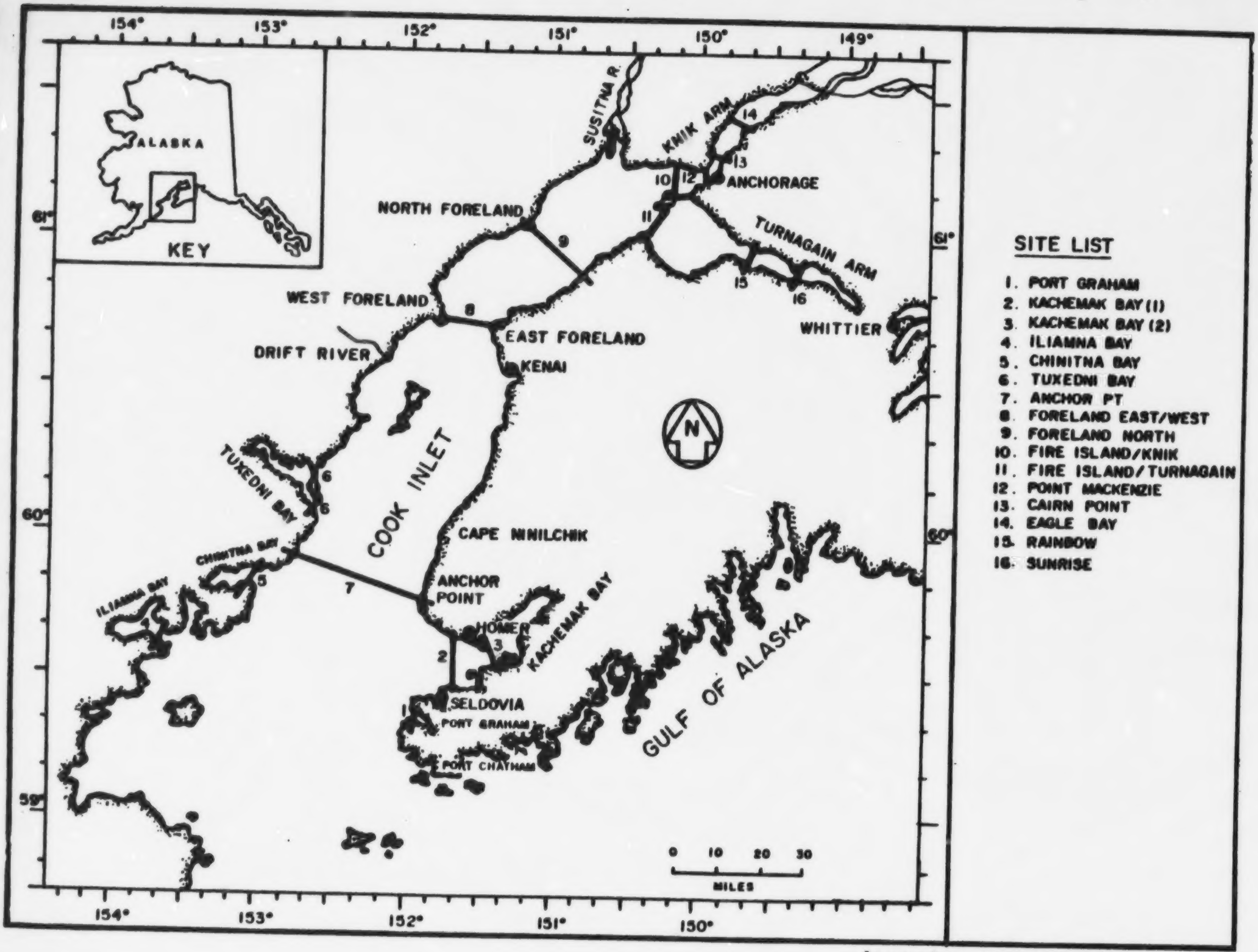
Figure D-17. Potential layout of selected plan for the International Passamaquoddy tidal power project.

auxilliary hydro-electric projects at Dickey and Lincoln School on the Saint John River in Maine. Congressional approval has never been forthcoming and other than an exploratory meeting at the official level, there has been no formal request for the necessary Canadian cooperation. In addition, a July 1965 report on the project, indicated that while the combined Saint John-Passamaquoddy project complex had a benefit to cost ratio of 1.8 to 1, Passamaquoddy itself had a b/c ratio of only 0.86. That report recommended "... continued study, re-examination, and possible redesign of the Passamaquoddy Project taking full advantage of the latest technological advances with possible reductions in capital costs". That is where the matter stands at this time.

Cobscook Bay: The United States government is, however, currently investigating the feasibility of exploiting the energy of Cobscook Bay only. The Bay, which is entirely within the United States, has an average tidal range of about 5.5 m and an area of 98 km^2 and could have an installed capacity of about 250 MW.

Cook Inlet: Cook Inlet, Alaska, also offers tidal energy exploitation possibilities (Figure D-18) with the two most attractive sites being in the upper reaches of the inlet, across either Knik Arm or Turnagain Arm.

A preliminary assessment of Cook Inlet tidal power potentials and characteristics, undertaken for the Governor of the State of Alaska, was completed in 1981. As a result of that preliminary assessment, it was concluded (Acres, 1981) that studies should proceed to evaluate those potential industries that would have a comparative advantage in association with a Cook Inlet tidal energy source and for the preparation of a conceptual development plan for the site above Eagle Bay on Knik Arm.


154°
153°
152°
151°
150°
149°
61°
60°
59°
ALASKA
KEY
SUSITNA R.
KNIK ARM
14
13
10
12
ANCHORAGE
NORTH FORELAND
11
9
TURNAGAIN ARM
15
16
WHITTIER
WEST FORELAND
8
EAST FORELAND
DRIFT RIVER
KENAI
N
TUXEDNI BAY
6
6
COOK INLET
CAPE NINILCHIK
CHINITNA BAY
5
7
ANCHOR POINT
ILIAMNA BAY
4
HOMER
3
KACHEMAK BAY
2
1
SELDOVIA
PORT GRAHAM
PORT CHATHAM
GULF OF ALASKA
0
10
20
30
MILES
SITE LIST
1. PORT GRAHAM
2. KACHEMAK BAY (1)
3. KACHEMAK BAY (2)
4. ILIAMNA BAY
5. CHINITNA BAY
6. TUXEDNI BAY
7. ANCHOR PT
8. FORELAND EAST/WEST
9. FORELAND NORTH
10. FIRE ISLAND/KNIK
11. FIRE ISLAND/TURNAGAIN
12. POINT MACKENZIE
13. CAIRN POINT
14. EAGLE BAY
15. RAINBOW
16. SUNRISE

Source: Acres American Inc. (1981)

Figure D-18. Potential tidal power sites, Cook Inlet.

A tidal electric plant at this location could have an estimated capacity of 1440 MW from 60 turbo-generator sets and 36 sluices with an annual energy ouput of 4037 GWh. The barrage would be formed by pre-fabricated powerhouse and sluiceway caissons. The assessment also concluded that tidal power development at Eagle Bay need not be dependent on the encouragement of industrial growth in the region since a viable scheme for meeting the most likely demand growth of the region is available if the energy could be retrieved economically.

APPENDIX E

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